Popular Astronomy.

Vol. I. **NOVEMBER, 1893.** **No. 3**

SHOOTING STARS.

How to Observe Them and What They Teach Us.

W. F. DENNING, BRISTOL, ENGLAND.

CHAPTER III.—RADIATION AND RADIANT POINTS.

The observer, having decided to commence observation and attended to the necessary preliminaries, will choose a dark, moonless night and, keeping a sharp watch on the sky, will proceed to register the paths of such meteors as make their appearance. After perhaps two or three hours of work he will imagine that the meteor paths are so irregularly distributed over the celestial vault that they are not to be reduced to any orderly arrangement. But carefully drawing their lines of flight backward he will find that most of them intersect at well defined points. These are called the "radiant-points" and they form a most important feature in the observation of meteor showers. A diagram will perhaps explain the matter more forcibly than mere description and so we subjoin a sketch in which a number of meteors are depicted with their lines of flight produced. Though the directions appear at first sight to be very discursive they resolve themselves into three well defined radiant-points.

It is the principle object of meteor observations to determine the positions of radiant points as exactly as possible and it is on this account that we have previously impressed upon the student the necessity of recording the directions of flight as accurately as possible.

The beginner may naturally feel inquisitive as to the nature of these radiant points. Do they each represent a planetary mass from which are discharged the individual shots seen every now and then? Other explanations may also occur to his mind, so we may as well state here that a radiant does not represent a material object but is produced by the effects of perspective on luminous bodies moving in parallel lines. It seems that meteoric particles (generally consisting of stony matter) exist in extensive shoals or swarms within (and probably without) the solar sys-

tem, and that they revolve in cometary orbits round the Sun. A number of these meteoric swarms cross the Earth's orbit and plunge into our atmosphere with planetary velocity, but the heat generated by friction immediately renders them incandescent and they are consumed in nearly every case before reaching the

FIG. 1—METEOR PATHS INDICATING MULTIPLE RADIANTS.

ground. We are perpetually suffering bombardment by thousands of these stony visitors and it is fortunate that they are robbed of their harmful character and that their material is exhausted by combustion while still at a considerable height above the Earth's surface.

The foregoing diagram will show how it is that visible meteors

as projected on the star sphere, take the form of radiations from a central focus:

Let us suppose the observer to be stationed at D, and that the sky-dome is represented at ABC. Six meteors moving in parallel paths and numbered 1, 2, 3, 4, 5 and 6, are shown and the furred portion of their tracks is intended to represent that observed. At certain points as at 1′ and 5′ they first become visible and disappear at 1″ and 5″. It is clear that the meteors will be apparently projected upon the sky as delineated at *a*, *b*, *c*, *d*, and that the meteor No. 3 will be motionless at the point *a*, which corresponds with the radiant, while No. 5 will have a pretty long path at *c*. In fact the paths will present a series of radiations and will appear to vary in length and speed according to position relatively to the radiant.

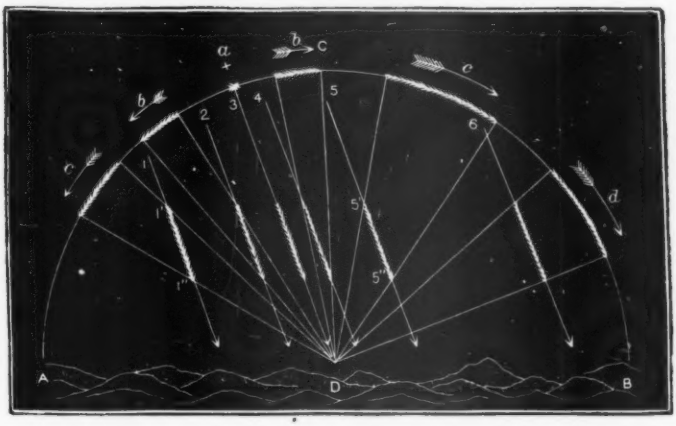


FIG. 2.

It may here be observed that radiant points partake in the diurnal motion of the firmament and are stationary amongst the stars—a fact which sufficiently proves their astronomical character. If they were due to the operations of a body within our atmosphere they would obviously be carried round with the Earth's rotation and make a complete circuit of the heavens once every twenty-four hours.

A great number of different radiant points are visible on every night of the year and their detection is sometimes a matter of difficulty. On about August 10 when the Perseids are most abundant, there are quite 100 distinct showers in active play.

Some of these are placed within a few degrees from each other, and they are only to be separated by a discriminating and accurate observer. Of course it is easy enough to get the radiant of a prominent display like the Perseids as the meteors are often very numerous and exhibit a good focus with only a few erratic flights. The subjoined diagram will give a good idea of the radiation from a strong shower monopolizing nearly all the meteors recorded.

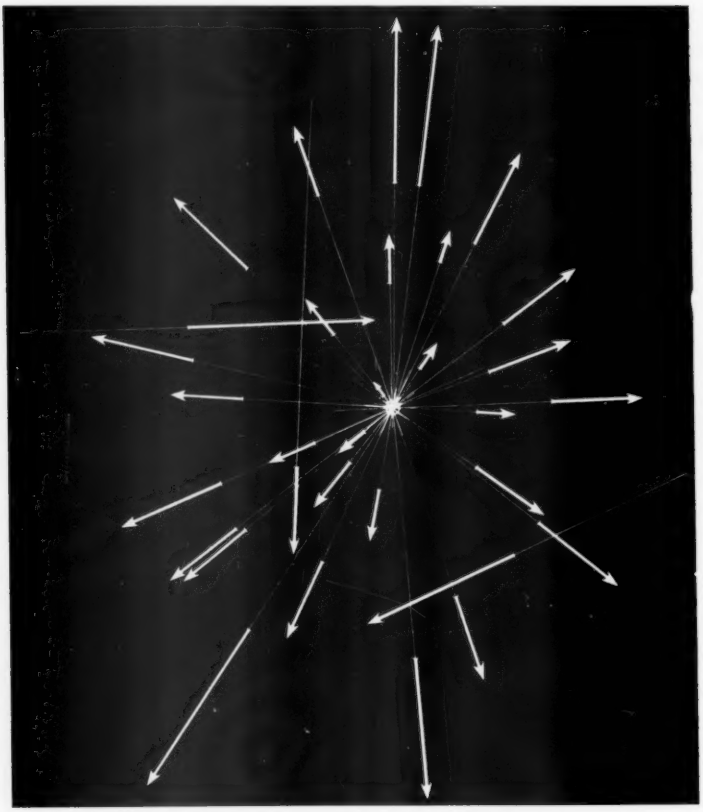


FIG. 3—PATHS FROM A RICH METEOR RADIANT INCLUDING THREE FROM OTHER SHOWERS.

A great difficulty always requiring the exercise of much discretion and care on the part of the observer lies in apportioning meteors to their correct radiants. This cannot be invariably

done as a meteor may be directed from several showers in the backward prolongation of its flight. From a single observation we only possess circumstantial or presumptive evidence that a meteor belongs to the radiant to which we have assigned it. We require therefore another "divining rod" beside that afforded by the path-direction. This is often to be found in the physical appearance of a meteor and observers should always, therefore, record the details of aspect presented by each object.

The Earth's motion in her orbit is approximately directed towards a point 90° preceding the Sun along the ecliptic, and this point is known as "the apex of the Earth's way." Meteors from showers in this region and within some 45° of it commonly move with great velocity and generate phosphorescent streaks in their paths These streaks often brighten up after the disappearance of the nuclei, in fact the writer has sometimes seen a streak come out in a spot where nothing was previously observed. Meteors from radiants far from the apex are slow and streakless though sometimes leaving trains of sparks, and the Andromedes of November 23-27 may be mentioned as an example of the slow trained meteors. Whenever a phosphorescent streak is left, we may depend upon it as proving the meteor to come from a radiant in the region of the apex (probably in the eastern sky) while a slow meteor with a train will as certainly have its centre in the region of the anti-apex in the S. or W. sky. The apex rises at about midnight and it will be advisable for the observer to know its position at different hours; this he may readily do by some naked eye star or other means.

A meteor with a long path frequently has its radiant near the horizon, and marked fluctuations of light are often characteristic of such a body. A radiant near the zenith usually supplies short meteors. A long-pathed meteor is always some distance from its center, while a very short, slow meteor will generally be close to it. A very dense streak or train left by a short meteor is a sure sign of foreshortening, as we see the spent material end on, and the radiant will probably be not more than a few degrees distant. A bushy appearance of the nucleus, or a sinuous curved motion, over a short arc are also indications of a foreshortened track. Long, rapid flights afford, on the other hand, clear evidence that the radiant is far away.

Hints like this are not perhaps without their value, but the best teacher, after all, is experience; and the young observer, in order to gain information as to these details, cannot do better than acquire them from nature herself by watching some well

known showers, such as the August Perseids and November Leonids, and noting the features of the individual meteors. Practical exercise of this kind is often more effective than any amount of description. The two showers we have mentioned are typical of the swift, streak-leaving meteors, so we would recommend the study of the November Andromedes as well, for they belong to a different class, moving very slowly and casting off trains of yellowish sparks. But the Andromedes do not come every year, nor do the Leonids return in strength except periodically; for this reason the August Perseids offer the best inducement, as they furnish a rich display every year, and are visible certainly from the middle of July to the middle of August.

Meteoric radiation is not always from a point; it sometimes constitutes an area of tolerably large dimensions. Thus during a brilliant exhibition of the Andromedes on November 27, 1885, the radiant was generally noticed to be very diffused. At Bristol the writer estimated its diameter as 7°. But this special shower cannot be accepted as typical of all. There are indeed many radiants which are sharply defined and certainly limited to one or two degrees. It is possible to distinguish such radiants with great precision. Perhaps one or two meteors out of ten will be a little erratic but the great majority of the paths intersect at a point. As a rule very diffuse, scattered radiants, or double radiants for one shower are simply the outcome of inexact observation. The bulk of the radiants determined at Bristol are certainly less than 3° diameter and the probable error in deriving a position is considered to be less than 2°. But a good deal must obviously depend upon circumstances. To get a thoroughly good position for a radiant the observed meteors must be near to it and must include paths nearly at right angles to each other so that both the R. A. and Decl. may be well ascertained.

THE SPECTROSCOPE AND SOME OF ITS APPLICATIONS.

JAMES E. KEELER.*

2. The Wave-length Scale, and the Solar Spectrum.

In the first number of POPULAR ASTRONOMY, I explained the principles on which a simple form of prism spectroscope is constructed, and showed how a bright-line spectrum is formed when the source of light is a body emitting certain definite kinds of rays. Experiment shows that a bright-line spectrum can be pro-

* Observatory, Allegheny City, Pa.

duced only when the source of light is a gas; thus we see at once that by merely looking at the spectrum of a body we can tell something about its physical condition. Under ordinary circumstances we should not need a spectroscope to tell us whether a body was gaseous or not, but if it were inaccessible,—if it were a nebula, for instance, millions of miles away in space,—even this amount of information might be in the highest degree interesting and valuable.

The particular arrangement, or grouping, of the bright lines, and their relative brightness, depend upon the kind of gas which gives out the light. If we suppose that each elementary substance, when vaporized by heat, has its own characteristic bright-line spectrum, which is the same under all circumstances, the reader will easily understand how the spectroscope can be used to analyze substances whose composition is unknown. It is only necessary to first become thoroughly familiar with the spectra of all the elements in order to recognize them when they occur together. In reality the case is not quite so simple as the one supposed, although near enough to it for the present purposes of illustration.

If a spectroscope like the one I have described, or a small pocket spectroscope, many of which are made by Mr. Browning, is pointed at the Sun or the bright sky near it, a spectrum very different from anything yet mentioned, will be seen. The bright continuous spectrum is crossed by multitudes of fine dark lines. Doubtless other and stronger lines will be seen, running *lengthwise* through the spectrum, but these are comparatively unimportant, being caused by particles of dust in the slit. Any small object, such as the end of a match, or a bit of paper, held in front of the slit, will show at once the origin of these lines. The vertical lines, (or those which are parallel to the slit), are of the greatest importance. If we suppose, as we safely may, that the light when it left the body of the Sun originally contained all possible kinds of rays, it is evident that some particular rays have been stopped on the way to us, or *absorbed*, either by the atmosphere of the Sun or by that of the Earth.

The dark lines in the solar spectrum were discovered by Fraunhofer, or at least their importance was first recognized by him, and the strongest lines are still known by the letters of the alphabet which he gave them for purposes of description. An acquaintance with these lines is indispensable to even the most elementary knowledge of spectroscopy, and hence it seems best to me to begin with a description of the solar spectrum, instead

of simpler forms which can afterwards be described more readily by means of the knowledge so gained.

It will first be necessary to explain the system which has been universally adopted for designating the position of a line in the spectrum. So far we have merely mentioned the color of that part of the spectrum in which the line is found, but this evidently gives only a very general idea of its position. To say that a line is in the green does not distinguish it from hundreds of other actual or possible lines. If the observer has a spectroscope provided with a graduated circle, he may measure the minimum deviation of the line, and thus determine its place in the spectrum with much accuracy. If, for instance, the minimum deviation of the line in the green is found to be 48° 45′ 30″, the line cannot be mistaken for any other in the spectrum obtained with that particular prism. The position so determined might be useful to the observer, but it would convey little information to anybody else, as the same line would be differently deviated by different prisms, and hence such a method as this is not suitable for general use. The same objection applies to all scales which are peculiar to the special instruments employed, and it is therefore necessary to find some method of stating the position of a line which is entirely independent of the instrument. The method universally employed is to give the wave-length of the light which is refracted to that part of the spectrum at which the line is found, or more briefly the wave-length of the line. To the beginner this may seem difficult, but in fact he will find the use of the wave-length scale is very simple, as all the hard parts have been done for him by others. It is not even absolutely essential that he should understand the principles involved in the method, just as a computer could use a table of logarithms without knowing how such a table is constructed, although doubtless he would use it all the better for such knowledge. The principles are not difficult, however, and I will proceed to their explanation, so far as they relate to the ordinary use of the spectroscope.

It is well known that light is an undulatory motion of the luminiferous ether,* a subtle medium assumed to fill all space. The molecules of a heated body are in a state of extremely rapid vibration, and their motion is communicated to the ether and propagated in all directions as light-waves, just as the vibratory motion of the particles of a bell is communicated to the air and propagated as sound waves.

* Certain difficulties are avoided by defining light as a sensation, generally caused by external agencies which are here regarded as light itself. The distinction is not often observed and it is entirely unnecessary for our purposes.

In a vacuum light travels at the rate of about 186,000 miles per second. In air the velocity is slightly less, and in glass it is reduced to about two-thirds of its velocity in space. As mentioned in the last article it is the retarding effect of glass that causes light to be deviated from its course by passing through a prism.

The average length of a light-wave is about $\frac{1}{50000}$ of an inch. The waves are not all of the same length, however. The shorter the waves, the more they are retarded by glass, and the more they are deviated from their original course by a prism. Hence it is that the rays of light are spread out by a prism *in the order of their wave-lengths*, the shortest waves going to the upper or violet end of the spectrum, the longest waves to the lower or red end, and other waves to intermediate positions according to a definite law. In the spectra formed by some remarkable substances, this regular sequence of wave-lengths is not found, but such substances are unfit for making prisms.

It is not customary to express the length of light waves in fractions of an inch. The unit in general use is the tenth-meter, which is the ten-millionth part of a millimetre. It is also called an Angström's unit, because it was adopted by Angström in constructing his large map of the solar spectrum. According to this system, the wave-lengths of lines in the visible spectrum range from a little less than 4000 tenth-metres, in the extreme violet, to a little less than 8000 tenth-metres in the extreme red, so that all lines will be indicated by intermediate numbers. The spectrum extends beyond these limits in both directions, but beyond them it is invisible.

The wave-length, of light in a vacuum, or in a medium of constant density are always the same, and it has been proposed to use them as a basis for constructing a practical standard of length; in fact the work of constructing such a standard is now going on in Paris.

The wave-length of a line therefore affords the best possible means of indicating its position, since the wave-length does not change and it is independent of the instrument used. The wave-lengths of all the important lines in the solar spectrum have been determined with extreme precision, not of course by direct measurement, but by indirect methods which are explained in works on optics. It is sufficient for our purpose to accept the results which have been obtained.

It is not necessary to think of the figures given for the position of a line as representing the length of the waves of light at that

point; on the contrary, it is more convenient to regard them as the reading of a scale fixed to the edge of the spectrum, and used to read off the positions of lines just as any actual and visible scale would be used. The only difference is that the figures on the wave-length scale have a special meaning, and those on an arbitrary scale have not.

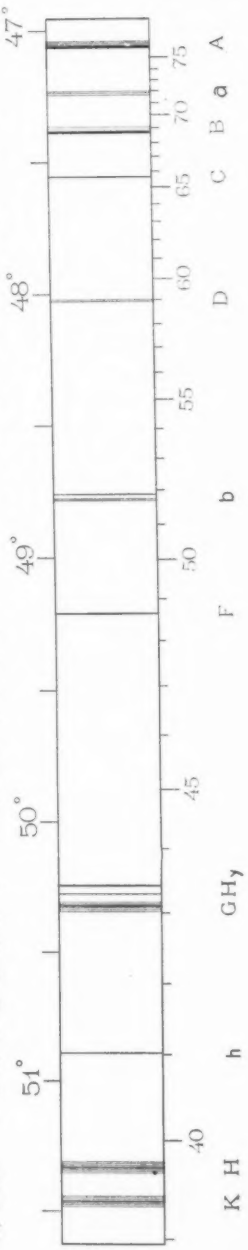
We are now ready to consider the solar lines in somewhat greater detail. The student should familiarize himself with their general appearance and arrangement, so that he can recognize them without difficulty. A rough-and-ready knowledge of the solar lines is like a knowledge of the constellations in studying the stars, while an accurate map of the solar spectrum and a list of the lines with their exact wave-lengths are to the spectroscopist what a star-chart and star-catalogue are to the astronomer. To learn the lines in the spectrum a map is necessary, and quite a number of fine maps have been published;—either original photographs, or engravings made from drawings. The photographic maps are to be preferred. They show us the actual solar spectrum as it is seen in an instrument, whereas in the others we are annoyed by errors which are unavoidable in drawing and printing.

But to the beginner the principal trouble with these maps (leaving aside the question of expense) is that they are on too large a scale, and they show too much. It is not easy to identify lines in a spectrum a few degrees long, seen in a small spectroscope with a low power, with the aid of a map which may be perhaps several feet in length.* To meet this difficulty Dr. Lohse, of the Observatory at Potsdam, published a map on a small scale, showing the lines visible with a small instrument. The student will find this map very convenient. It is in No. 6 of the second volume of the Potsdam Publications.

As all who read this article may not have access to Dr. Lohse's map, I have drawn the accompanying figure, which will perhaps be useful in the same way, although it contains only a few lines. It represents the relation between the principal Fraunhofer lines, their wave-lengths, and their deviations by a 60° glass prism used at the Allegheny Observatory, and it is accurately drawn to scale. The deviations will certainly not be the same for any other prism, and the spacing of the lines will also be slightly dif-

* I find it a time-saving device to color a thin strip along the edge of a map with crayons or water-colors so as to approximately match the tints of the spectrum. When the map is printed on many separate sheets the desired part can be selected at once without looking at the figures. Colors are also useful on a long catalogue of wave-lengths.

ferent; still the figure will represent quite closely the distribution of the same lines in the spectrum given by any small instrument. The degrees of deviation are marked above the spectrum, and they are, of course, of equal length. The wave-lengths are marked below in intervals of 100 tenth-metres, (the last two ciphers being omitted for economy of space), and the reader will notice at once that the intervals are unequal, being much longer in the violet (or left hand) than they are in the red. The distribution of light-waves shown in the figure is characteristic of the prismatic spectrum. It is evidently the result of some law, but the real physical law has never been satisfactorily made out, although an arbitrary formula may be determined for any given prism which will represent the spacing of the wave-lengths with all necessary precision.



If we should draw the wave-length intervals all equal, and plat the Fraunhofer lines in their appropriate places on the scale so obtained, we should have what is called a *normal* spectrum. Such a spectrum can be actually produced, although not by means of prisms. As compared with the normal spectrum, the prismatic spectrum is evidently much compressed in the red and spread out in the violet.

With the aid of the diagram, I will now attempt to describe the principal Fraunhofer lines, so that the reader can recognize them in the actual solar spectrum, which he is supposed to be observing with his small instrument. I shall also give the known origin of the lines, although we have not yet considered the way in which they are determined, and the exact wave-lengths, as they will be useful hereafter.

Perhaps the most easily recognized line in the spectrum is the close double line marked D, and the reader may begin by looking

for it. It is in the orange part of the spectrum, just below the yellow, and there are no other strong lines in its vicinity. To see the D line double with his small instrument, the observer may have to direct the collimator to the Sun itself and make the slit very narrow, and also focus the telescope carefully. The D lines are just six tenth-metres apart, their wave-lengths being 5890 and 5896. The lower one (down always meaning toward the red) is called D_1 and the upper one D_2. They are caused by the absorptive action of sodium vapor in the Sun's atmosphere, and if any difficulty is experienced in finding them in the spectrum, the sodium flame described in the last article, when held in front of the slit, will point out their exact places, for it will give two ***bright*** yellow lines which coincide exactly in position with the dark D lines.

With a more powerful instrument, a fine line can be seen nearly midway between the D lines. It is due to nickel.

Passing down the spectrum, the first strong line we come to is C, in the bright red, or scarlet. It is due to hydrogen, and is an important line in solar spectroscopy. The wave-length of C is 6563.

This is nearly the end of the spectrum if our instrument is pointed to the sky, but if we turn it to the Sun we can see much lower. In the full, deep red we come to B, which looks like a strong dark line with a shade on its lower side. With a very powerful instrument the strong line is resolved into a large number of dark lines, and the dark shading into a most remarkable series of doublets, diminishing in intensity toward the lower end of the spectrum. The B line with its attendant doublets is due to the absorptive action of our own atmosphere, and more specifically to oxygen. No single wave-length can be given for the B line; perhaps the part which would be called its centre with a small instrument is at wave-length 6874.

Below B, at the extreme lower end of the spectrum is the great A line, in appearance much resembling B, although it is darker and stronger, and in a powerful instrument the series of doublets below it is even more remarkable than the corresponding attendants of the B line. The broad dark head is resolvable into a group of lines, the centre of which is at about wave-length 7604. The A line is caused by the absorptive action of oxygen in the Earth's atmosphere.

To see the A line well, the spectrum should be viewed through a piece of deep blue (cobalt) glass, which seems to cut off the diffuse light in the field. It may seem strange at first sight that the blue

glass should be preferred to red. The reason is that the blue glass transmits the extreme red of the spectrum (as well as the blue and violet light), and absorbs the yellow rays which cause most of the glare, and which are transmitted by red glass. Drawings of both the A and B groups on a large scale, by Professor Langley will be found in the Proceedings of the American Academy of Science, 1878.

Between A and B are many smaller lines, the most prominent group of which is called *a*. Most of the lines are atmospheric.

Going back to D, and passing up the spectrum, in the bright green we come to *b*, a close group of lines. The strongest lines are designated b_1, b_2, b_3, and b_4 beginning with the lowest one, and their wave-lengths are respectively, 5184, 5173, 5169 and 5167 tenth-meters. A small spectroscope will not separate the lines very well. b_1, b_2 and b_4 are due to magnesium. In a large spectroscope they have hazy borders. b_3 consists of two very close iron lines.

F is a strong line just about on the boundary between the green and the blue. It is a hydrogen line, the second in a regular series which begins with C. Its wave-length is 4861.

Above F the lines become very numerous, and are not always easy to identify. G is the strongest line in a rather wide group, which is only roughly indicated in the figure. Below the group in which G is situated are two rather strong lines; the lower line is Hγ, sometimes called *G* (italic), the third line of the hydrogen series. It is an important line in astronomical spectroscopy, for the reason that it occurs in nearly all star spectra, and it is in the part of the spectrum which most strongly affects the ordinary dry plate used in photography. The wave-length of G is 4308, and that of Hγ is 4341.

Another hydrogen line, *h*, is found at 4102 on the wave-length scale.

H and K are two broad, hazy lines, easily recognized at the extreme violet end of the spectrum, and are best seen with the aid of a piece of blue glass. Both are due to calcium in the Sun's atmosphere. The fourth line of the hydrogen series falls so close to the calcium line in the center of H that it cannot be separately seen. The wave-lengths of H and K (the central calcium lines) are 3969 and 3934.

The lines which have been mentioned take us through the whole range of the visible solar spectrum. The way in which lines in the invisible parts of the spectrum are detected must be left until another time.

It should, perhaps, be mentioned that the tenth-metre is not invariably chosen as the unit of the wave-length scale. Sometimes a unit ten times greater—the millionth of a millimetre—is used, and then the wave-length of the F line would be written 486.1; some writers use the *micron* or thousandth part of a millimetre, and write the wave-length of F, 0.4861. As no line in the visible spectrum has a wave-length ten times greater than that of any other line, no confusion results from this practice. To indicate that a number represents a wave-length, the symbol λ, which always stands for wave-length in optical formulæ, is written before it; as λ 4861.

In closing the subject for the present, I will mention, for the convenience of the reader, some of the more important maps of the solar spectrum that have been published.

Fraunhofer's original map was printed in the *Denkschriften* of the Munich Academy of Sciences, 1814-15. On account of its great historical interest, it is often reproduced in modern text-books; there is a copy, for instance, in Lockyer's "Solar Physics," and another (not showing the whole spectrum, however) in Young's "The Sun".

The original map by Kirchhoff, the discoverer of the natural laws which underlie the phenomena exhibited by the spectroscope, was published in two parts (four plates) in the Transactions of the Berlin Academy, 1861 and 1862. It extends from A to G, inclusive. The accompanying memoirs were translated into English by Professor Roscoe and published with the plates by Macmillan in 1862 and 1863. The instrument with which this great work was executed has four prisms; otherwise it is much like the simple spectroscope described in our last article. It is now in Chicago, in the German educational exhibit of the gallery of the Liberal Arts building. The scale of Kirchhoff's map is an arbitrary one. Lines are still sometimes designated by their place on this scale; as for instance a certain line in the spectrum of the Sun's corona, which is generally known as 1474K. The wave-length of the same line is 5317.

Angström's memoir on the solar spectrum was published at Upsala in 1868. The map, extending from a little below B to K, occupies six plates, and the scale is a *normal* one. Recent researches have shown that the scale readings all need to be increased by just about one division, or tenth-metre. Angström's scale has hitherto been used as a standard in spectroscopic work. A reduced copy of the map is given in a number of text-books, as in Kayser's "Lehrbuch der Spectralanalyse" and Schellen's Spectrum Analysis".

Rutherford's fine photographic map of the normal solar spectrum from *b* to λ 3550 in the ultra-violet was published in 1875, and has been in turn surpassed by Professor Rowland's great map, showing the whole solar spectrum, from below the B line to far in the ultra-violet, on an immense scale. It is mounted on ten separate sheets, and if stretched out so as to form a continuous strip would make a solar spectrum about forty feet long.

Among other maps may be mentioned the following: a magnificently engraved map by M. Thollon, extending from below A to and including the *b* group, left incomplete by the death of the observer, published in Vol. III of the Annals of the Observatory of Nice. The scale is arbitrary; Professor Piazzi Smyth's elaborate and somewhat diagramatic maps, in the Transactions of the Royal Society of Edinburgh; Dr. Becker's map showing the spectrum of the high and of the low Sun, in the same Transactions (Vol. 36, Part I), and Mr. Frank McClean's photographic map on the same plan. Selected portions of a photographic map by Mr. George Higgs of Liverpool, showing wonderful definition, are reproduced in *Knowledge*, Sept. 1, 1890. I am not aware that the complete map has yet been published.

SUGGESTIONS TO AMATEURS, NO 2.

LEWIS SWIFT.

The Great Nebula in Andromeda.

When, some 150 years ago, a few nebulous bodies were resolved into stars by the small telescopes then in use, the opinion generally prevailed that, could glasses of sufficient size and power be brought to the work, all would be found resolvable, and, as telescopes were increased in size, and more and more showed themselves to be masses of stars, the idea seemed a not unreasonable one, though, at the same time, a great number were discovered which defied even the mammoth telescopes of Sir William Herschel, so that while but few were added to the list of resolvable nebulæ, a vastly greater number were still unresolvable and the question whether all nebulæ are really star clusters was held in abeyance. It required the invention of an optical instrument entirely unlike the telescope, viz., the spectroscope, which by analysis of their light has settled the matter in a manner both emphatic and unexpected, though it cannot here be described, being alien to the subject I have assumed to discuss.

Only about a half dozen nebulæ are visible to the naked eye. One of the brightest and largest, though by no means the nearest is the great nebula in Andromeda, commonly so called, which though telescopically a nebula is spectroscopically a star cluster, that is to say, the spectroscope shows it to be an aggregation of, probably, countless millions of suns, and yet no telescope has ever resolved it into stars. It may equal or even surpass our Milky Way in grandeur. It has two companions, one a cluster, the other a nebula, both of which are, with large telescopes, superimposed on the face of the principal, though we cannot say whether either belongs to the lucida, or if one or both are between us and it or beyond.

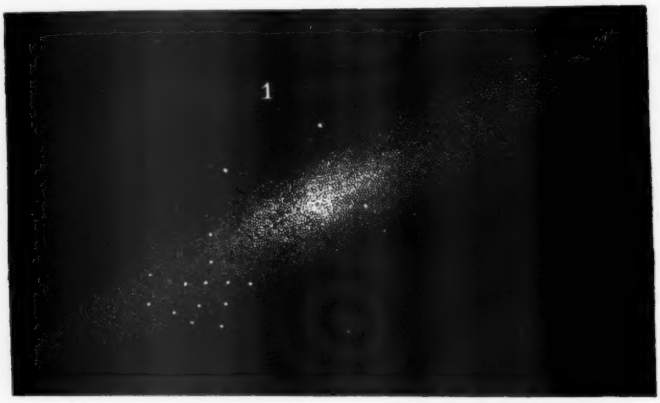


FIG. 1.

Through small and even pretty large telescopes it appears as a long, narrow ellipse of undeviating regularity, but in great instruments the elliptic symmetry is lost.

Its position is right ascension $0^h\ 36^m\ 56^s$; declination north 40° 41′. It is known as No. 31 of Messier's Catalogue of 103 nebulæ, published in 1781. To the naked eye it presents no particular outline, but seems simply a hazy spot and has often been mistaken for a comet.

To find it, look at Alpha Andromedæ, the pretty bright star forming the northeast corner of the square of Pegasus. Fifteen degrees northeast is another star nearly as bright, and about five degrees north and a little west of the last named is the faint star Nu, (ν) close to which is the nebula.

Under favorable conditions of seeing, my telescope, a 16-inch

PLATE VII.

THE NEBULA IN ANDROMEDA.

Photographed by Mr. Roberts Dec. 30, 1888.

Copied from *Himmel und Erde*.

refractor, shows it extended to four degrees in length and two and one-half in breadth with little symmetry of outline, and having two dark streaks or lanes running lengthwise across its face, which latter a long exposure of the photographic plate shows to be rings, suggesting the rings of Saturn. That it is a double annular cluster seen partly edgewise is in the highest degree probable.

Fig. 1 shows it as it appears through my 4½ inch comet seeker.

Fig. 2 as seen with my 16-inch refractor.

Plate VII. (Opposite) as photographed by Mr. Roberts.

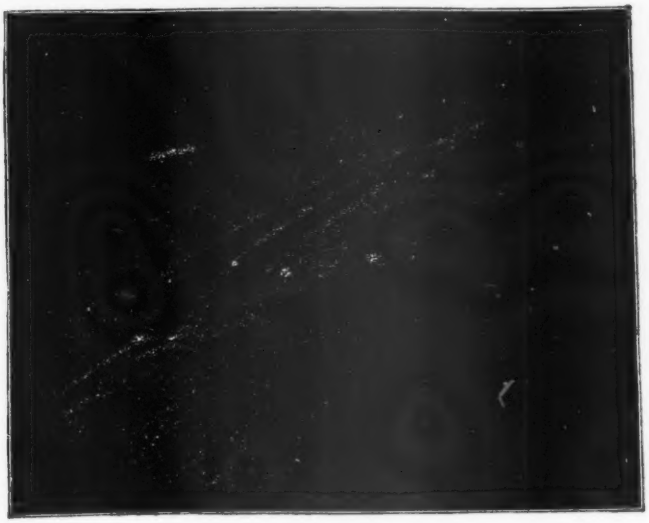


FIG. 2.

The most casual inspection shows a difference so enormous that it is difficult to believe them representations of one and the same object. Unlike most of the illustrations in astronomical text-books these are correct. How difficult it is to make lifelike drawings of nebulæ only those who have attempted their delineation know, and to argue, as has been done, change of physical contour because of dissemblance by different draughtsmen is almost absurd.

The central portion of this nebula is very bright. An examinatian of Fig. 2 will show the two companions which are within the visible boundaries.

The bright points scattered over the plate are stars or self-shining suns like our own, each doubtless, the center of a planetary system where beings like ourselves may dwell. There lies before me as I write a photograph of the nebula and its surroundings by Dr. E. E. Barnard of the Lick Observatory, where sixty-four thousand Suns are distinctly visible. It was not, as might be supposed, taken with the great telescope, but by a photographic camera of five inches aperture lashed to the declination axis of a six-inch telescope, the latter being employed simply to obtain the service of its driving-clock, and, to check the irregularities of its rate, the photographer for 4^h 18^m holding the cross wires of the telescope exactly on a selected star in order that the stars might show as sharp points rather than blurred dots. It is a grand piece of photographic work not merely, but also an example of the unwearied patience of one who but a few years ago belonged to the class I am now addressing, viz., amateur astronomers, but who by untiring energy has achieved a standing which excites the admiration of the world.

This nebula was first discovered of course by the naked eye about a thousand years ago, and as it was then, as now, an inconspicuous object to the unassisted eye, we infer that very little if any change in position or brightness has occurred. In 1885 a new star suddenly shone out from almost the exact center of its brightest portion. When it had attained its maximum brilliancy it was of nearly the sixth magnitude but in a few weeks had so declined as to require a good telescope for its viewing. I well remember on the occasion of my last quest for it, how extremely difficult it was to even glimpse it with my 16-inch glass, though but a few weeks before I had seen it on a single occasion with the naked eye, much extraneous light being shut out by a dense grove of trees. It has not reappeared since nor ever may. By what dire calamity such a torch could be suddenly lighted and so quickly extinguished is only one of the many mysteries of astronomy. And what relation, if any, the star bore to the nebula is also unknown. And though light moves at the rate of 186,300 miles per second, the event must have happened many years before the tidings of the awful disaster of a world on fire reached our planet.

Text-books declare that the late Professor Bond with the 15-inch refractor of Harvard College Observatory saw 1,500 stars on the face of the nebula. With a larger telescope I have been unable to detect so large a number, but, whether they be less or

more, they appear to have no connection with the nebulous cluster, but to lie between us and it.

Sir William Herschel is said to have estimated that 100,000 years would be required for the light from the stars of this cluster to reach us, but as its distance is unknown the fallacy of such an argument is apparent, and, I doubt if the distinguished astronomer so averred. But the fact that the spectroscope emphasizes it to be a cluster, while the greatest telescope yet made cannot resolve it, certainly betokens a distance incomprehensible to finite minds.

WARNER OBSERVATORY, Rochester, N. Y.

Sept. 21, 1893.

CONSTELLATION STUDY.

WINSLOW UPTON.

III.

In the preceding article attention was called to the difficulties in learning the constellations which arise from the daily motion of the heavens. Were the stars always in the same part of the sky, it would not be a difficult matter to fix their positions so firmly in the mind that they would be recognized just as we recognize the familiar objects near our homes. But the daily rotation of the Earth on its axis prevents any such recognition, and we are obliged to learn them, if we learn them at all, in their varying positions from night to night. This difficulty is aggravated by the fact that the axis of rotation is inclined to the vertical position in which we stand when looking at the sky, so that the groups seem to turn as they move from east to west. The farther north the constellations lie, the more marked is this change. Thus Scorpio, low in the southern sky, does not change its angle with the horizon so much in moving from southeast to southwest as to render its recognition difficult, but Draco, a winding constellation high in the northern sky, is quite hard to find in its varying positions around the celestial pole. This difficulty, however, soon ceases to be troublesome if the student is persevering and systematic. He must be persevering in order to see a given group in all its positions, for this requires noting it from time to time for several months. He must also be systematic in order to learn the group not as an isolated collection of stars, but as related to neighboring groups; if he is

careful in noting these relations he will find it comparatively easy to remember the groups, and he will not be much disturbed by the changes in position from night to night. He will also verify for himself the fact that the heavens turn as a whole, and that in consequence the relative positions of the configurations are unchanged, no matter in what part of the sky they are viewed.

It was suggested in the preceding article that a systematic study of the constellations could be made on the basis of the divisions of the heavens made by professional astronomers in designating the places of stars in star catalogues and charts. The advantages of this plan are sufficiently obvious to need no further discussion, and, as was pointed out, there are certain prominent stars which mark the boundaries of the several subdivisions with sufficient precision for this purpose. This is preeminently true of the stars which mark the position of the equinoctial colure, which corresponds in the celestial system to the meridian of Greenwich on the Earth as a reference circle. It will be remembered that the names *declination* and *right ascension* are used for designating star places, and not latitude and longitude to which they respectively correspond.

It is a good plan to go out into the open air and looking up at the sky imagine the surface of the sphere covered with a system of circles corresponding with those we draw upon the celestial globe. We are accustomed to view the latter from the outside, looking down upon the convex surface. In celestial observation we are within the sphere, at its very center apparently, and look up upon the concave surface of a sphere. On this concave surface imagine the system of circles drawn, corresponding exactly to those on the globe, but with only half of the system visible in the hemisphere above us. Around the north star, or more accurately the north pole, imagine a series of small circles drawn, like the parallels of latitude, larger and larger as one goes south until the horizon cuts off part of the circles imagined. When the circle passing through the east and west points of the horizon is reached, it will be exactly halved by the horizon, just half of it in the visible and half in the invisible hemisphere. It will be noticed that the planes of all these circles are inclined to the horizon because they are all perpendicular to the line joining our eyes with the pole. In consequence, the circle just mentioned, which passes through the east and west points of the sky, does not go through the zenith or point directly overhead, but crosses the meridian at a point as much south of the zenith as the pole is elevated above

the north horizon (the latitude of the observer's station). This circle is the celestial equator. Continuing to imagine circles, drawn farther and farther south, it will be seen that more than half of the circles are invisible, and that the portion visible is smaller and smaller until the south point of the horizon is reached. If any difficulty is found in imagining these circles, the daily motion of the heavens will trace them for us. Simply select the Sun, the Moon or any star and look at its place occasionally for a few hours, and it will show just how the circle upon which it is placed lies in the sky. These circles are sometimes called parallels of declination, to correspond with parallels of latitude on the Earth, and sometimes, quite appropriately, diurnal circles for the reason just given.

Continuing the construction of the system of circles on the concave surface of the sphere, we now imagine an indefinite number of circles to diverge from the north pole in all possible directions, like the meridians on the Earth. They will all cross the celestial equator at right angles and then converge, all meeting at the invisible south pole of the heavens. The system is now complete; all that remains is to select one of these circles for a circle of reference—that passing through the points on the celestial equator where the Sun is at the vernal and autumnal equinoxes. This reference circle,—the equinoctial colure,—can be easily traced in the sky, as explained in the last article, by the line of bright stars α Ursæ Minoris, β Cassiopeiæ, α Andromedæ and γ Pegasi leading to the vernal equinox, and α Ursæ Minoris, δ Ursæ Majoris leading to the autumnal equinox.

The reader of these articles, who is following the suggestions made for a first study of the constellations, is advised at this point to recall the definitions of right ascension and declination, and to estimate the right ascension and declination of certain objects in the sky, for instance the planet Jupiter, the Moon, or some star which is already known, as α Lyræ. To do this, first imagine the celestial equator, and then the circle passing from the pole through the object to the equator; then estimate the distance between the equator and the object measured on this circle in degrees, calling the whole distance between the pole and the equator 90°. This is the declination. Next find the line of stars tracing the equinoctial colure, and estimate the angle between this circle and the declination circle just drawn between the pole and the object. This is the right ascension. The angle should be reckoned from the part of the equinoctial colure passing through the *vernal* equinox towards the east un-

til the declination circle of the object is reached. For instance in the autumn evenings the line of stars marking the half of the equinoctial colure which leads to the vernal equinox is high in the sky, coinciding with the meridian at about 9:30 P. M., Nov. 1st., and 7:30 P. M., Dec. 1st. Any object in the eastern sky, as the planet Jupiter this year, has a right ascension less than 90°.

If the object is, however, in the western sky, like α Lyræ, the angle between the equinoctial colure and its declination circle reckoned towards the east will be greater than 90°, in fact greater than 180° or even 270°. A good way in such a case is to reckon backwards or westward from the equinoctial colure and then subtract the estimated angle from 360°. The Moon is an excellent object to make these estimates upon, as it will be found each night about 13° east of its position the preceding night. Its right ascension will therefore increase from night to night until it has completed the whole 360°. At the same time its declination will vary between 28° north and 28° south of the equator. It is the present custom of astronomers to give right ascension in hours, minutes and seconds, like the ordinary time division of 24^h, rather than in degrees, minutes and seconds, but both are in current use. Dividing or multiplying by 15 will evidently change the one method to the other.

There are two difficulties frequently encountered by the student which may here be discussed—that of remembering the groups after they have once been learned, and that of using star maps. The former difficulty is not peculiar to astronomical study. Some one has defined the Memory, as "the faculty by which we forget things." Theorists may tell us that when we once thoroughly understand and learn anything we should never forget it; but practical experience shows that it is necessary to think occasionally upon the subject if it is to be remembered. And so with the constellations. In order to remember them it is necessary to review them occasionally. It is a good plan to form the habit of looking up at the sky frequently on starlight evenings and recall the groups, and if any are seen which are not at first recognized, to look them up upon a star map and thus restore them to their place in the mind. The more frequently this is done the better will the groups be remembered, provided they are thoroughly mastered at the outset.

The other difficulty can be overcome only by practice in the use of star maps, but it is not a serious difficulty except at first. It results from the fact that the star map is necessarily upon a flat surface and so the stars must be located on the map by some one

of the various methods of projection of a spherical surface upon a plane. Besides, black stars printed upon a white paper background do not look like white stars seen upon the dark ground of the sky. Some maps have been prepared with white stars upon a blue or black surface to remedy the latter difficulty, but the result has not met with much favor, and maps are to-day usually made with black stars printed upon a whitish paper. This difficulty disappears with a little practice and soon one can readily pass from the map to the stars or from the stars to the map with facility.

There is one way in which the two difficulties just named can be further reduced and which is also an excellent aid in the first learning of the constellations. It is by making star maps one's self as the several groups are learned. This involves some labor but not so much as one might at first think, and it is a labor which in the opinion of some is well spent, for the mere act of plotting upon a page the leading stars of a group tends to fix them the more firmly in the memory, and it accustoms the learner also to the habit of locating points by their relative positions, and at the same time gives facility in using star maps. The rest of this article will therefore be given to an explanation of a method by which students' star maps may be simply constructed as an aid to learning the constellations.

In order to prepare star maps, it is necessary first to have blank maps prepared upon which the stars are to be inserted, and second to have the positions of the stars given with sufficient accuracy for the purpose of plotting them. The blank maps would better be five in number, one for each of the four divisions of the heavens made by the equinoctial and solstitial colures, and the fifth for a polar map made by taking from each of the four the part near the pole. This division is suggested by the ordinary position of the student as he views the heavens. For studying those constellations which lie between his zenith and the southern horizon he faces the south, turning occasionally towards the east or west; the west lies on his right and the east on the left. When he looks at the northern constellations, he faces the north in his average position, and in middle latitudes observes the groups which are usually known as circumpolar groups—those which do not rise and set but are always above the horizon. The polar constellations seem to him to be revolving about the pole in a direction contrary to clock hands. Makers of star maps usually have one or more maps in which the pole is at or near the centre of the map, and others for the parts of the sky ly-

ing farther away from the pole corresponding to the view of the sky when the observer faces the south. Let us now note how such maps can be constructed.

1. *The Polar Map.* This should cover that region about the pole in which the stars do not rise or set. For all middle latitudes it is sufficient to select the region which is within 45° of the pole. Select any convenient radius, for instance 6 inches, and describe a circle. Draw two diameters at right angles to each other and let them represent the equinoctial and solstitial colures. Then draw a series of smaller circles concentric with the first one drawn, to represent the parallels of declination.

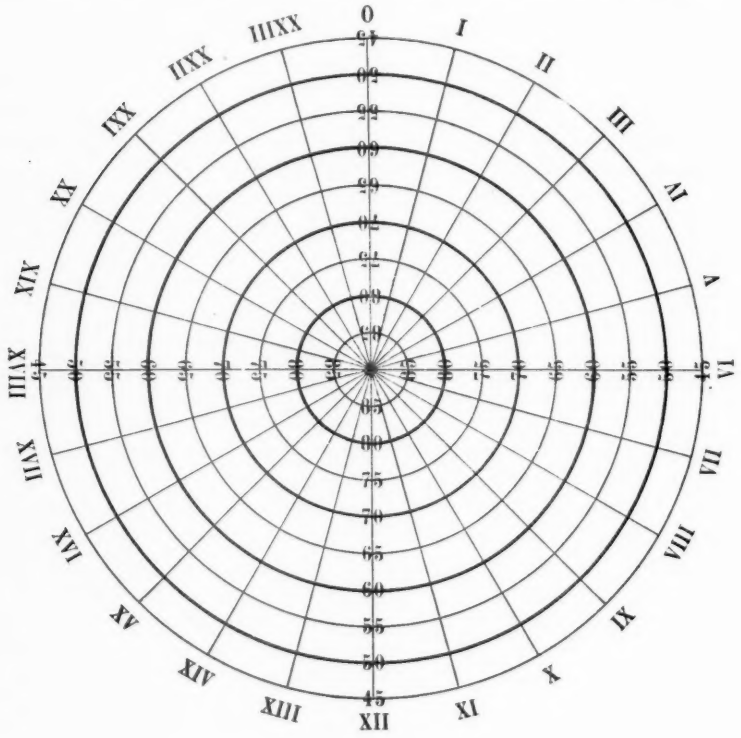


FIG. 1.

For the purpose of plotting the leading stars of the constellations it is advisable to draw these circles for every five degrees of polar distance. Their radii will then be one-ninth, two-ninths,

etc., of the original radius. At their intersections with the equinoctial and solstitial colures it is well to write the degrees of declination 85°, 80° and so on to 45°. Then, other diameters should be drawn; if they are placed 15° apart they will accord with declination circles an hour apart in right ascension. They should be numbered from the diameter selected for the equinoctial colure, around the circle in the direction in which the hands of a clock move.

Fig. 1 represents a polar map thus drawn in outline. It was drawn on a scale one-half of that suggested, and has been reduced somewhat in printing. For practical use, a larger size is advisable and the suggested size of 6 inches for the length of the radius is none too large. It requires a sheet of paper somewhat more than 12 inches square. Several minor suggestions in the construction of the map may be made. Contrasts in the heaviness of the lines will make the map easier to use; thus the smaller circles at the even 10° may be made heavier than the others, and the diameters which mark the hours of right ascension may be of different strength. The two colures should be especially prominent so that the division into quarters may be conspicuous. If the size of the sheet admits, it may be well to insert circles or diameters at intervening distances, and these may be made by dotted lines. Experience will show whether the skeleton map prepared as above is more useful without or with more reference lines.

The use of such a map needs but a brief explanation. It is for the insertion of the prominent stars of the polar constellations in their proper positions. Thus a star at 65° declination and 20^h right ascension would be placed at the intersection of the 65° circle with the 20^h declination circle. A star at 73° declination and $5^h\ 40^m$ right ascension would be placed between the 70° and 75° circles and the 5^h and 6^h declination circles at the proper distances. The seven stars of the Dipper have the following positions:

		Right Ascension.		Declination.
		h	m	°
α	Ursæ Majoris	10	57	62.3
β	" "	10	56	56.9
γ	" "	11	48	54.3
δ	" "	12	10	57.6
ϵ	" "	12	49	56.5
ζ	" "	13	20	55.4
η	" "	13	43	49.8

When an outline polar map has been constructed, it would be a good plan to insert these stars for practice in its use.

2. *The Equatorial Map.* This map should contain for each of the four divisions of the sky the space south of the boundaries of the polar map (45° in declination if drawn as above suggested), to the limit of the visible heavens. It may be easily constructed on the plan illustrated in Fig. 2, as follows: First two lines at right angles to each other are drawn of the same length, which may well be the diameter of the polar map,—for instance twelve inches. One of these is chosen for the equator and the other for the central declination circle of the section. Parallel lines to the equator are next drawn at distances of every 5° in declination.

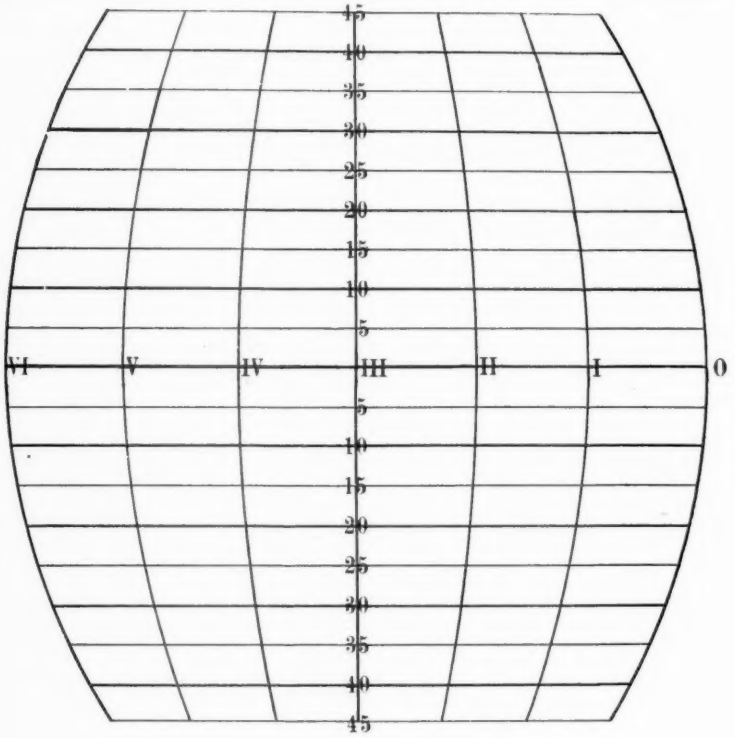


FIG. 2

Their distance apart will be the same as that of the parallels of declination of the polar map. Their length will be shorter and shorter as the distance from the equator increases, according to the values to be given below in a table. These parallels of declination are to be numbered for declinations from the equator north

and south. When the lengths of the parallels of declination have been carefully laid off, the right and left boundaries of the map may be drawn by the eye. or they may be drawn by dividers, one leg placed upon the equator at a distance 1.85 times the half length of the line representing the equator. This latter construction will not pass exactly through the terminal points of the parallels of declination, but quite near enough for the purposes of the map. The right and left boundaries thus drawn represent the portions of the equinoctial and solstitial colures included within the map. Intermediate declination circles may be easily inserted; if for each hour of right ascension as in the polar map, the equator and each parallel of latitude will be divided into sixths, and the curves drawn by the eye.

Fig. 2 was drawn on the above plan with the length six inches for the two lines first drawn, and has been somewhat reduced in printing. The double size, 12 inches, is advised for practical use, corresponding with that of the polar map, and requiring paper somewhat over 12 inches square, according to the margin desired. The declination circles for the 0h, 1h, Vh and VIh were drawn with dividers as arcs of circles, those for IIh and IVh were drawn by hand through the points of intersection of the several parallels of declination, each one-third the length of the parallel from the central vertical line. The numbering of the declination circles should be from right to left as in the figure, since right ascensions are reckoned toward the east, which is at the left when the observer faces the south.

The reader familiar with trigonometry will understand that the lengths of the several parallels of declination equal the length of the line representing the portion of the equator multiplied by the cosine of the declination. The curves representing the declination circles should strictly be arcs of ellipses, but if drawn as arcs of circles the error introduced is too slight to be noticed for the purpose at hand.

It will be well to give the lengths of the several parallels of declination in the form of a table. They are calculated on the supposition that the line representing the portion of the equator included in the map is twelve inches in length, that is six inches on either side of the vertical line. One-half of the given values represents the length on either side of the vertical line, and one-sixth represents the distance between the declination circles drawn one hour apart.

Table showing the length of the lines representing the parallels of declination, their half-length, and one-sixth their length, assuming a scale of 12 inches for the equator represented:

Declination.	Length.	One-half length.	One-sixth length.
°	in.	in.	in.
5	11.95	5.98	1.99
10	11.82	5.91	1.97
15	11.59	5.80	1.93
20	11.28	5.64	1.88
25	10.87	5.44	1.81
30	10.39	5.20	1.73
35	9.83	4.91	1.64
40	9.19	4.60	1.53
45	8.48	4.24	1.41

In the above table the fractions of an inch are expressed decimally, but if any one has an ordinary scale in which the fractions are in sixteenths of an inch, the above decimals can be turned into sixteenths before using.

The use of the equatorial map is precisely the same as that of the polar map. Four skeleton maps are to be prepared, one for each of the four divisions of the sky. If the work of preparing these outline maps seems too great, two may be made, *viz.*, the polar and one equatorial, and a test made of their advantages in constellation study before the others are drawn.

A necessary adjunct to the outline maps is a list of stars to be inserted with their right ascensions and declinations. In the following articles of this series the positions of the leading stars in each constellation will be given. In order to make the plotting of the stars aid the memory in retaining the configurations it is advisable not to plot them until the constellation group is learned, and after the leading stars are inserted by their positions, to look at the sky again; if any other stars of the group seem necessary to complete the characteristic figure of the group, these may then be inserted by their relation to those already charted.

The outline maps described above are simplified forms of two well known projections, the stereographic for the polar map and the orthographic for the equatorial map. The construction of maps on the strict principles of these projections would be too difficult and quite unnecessary for the purpose proposed. These maps do not differ materially from those used in Burritt's Geography of the Heavens—a star atlas which did much good service years ago. The projections are not of sufficient accuracy for use in a complete atlas of all stars visible to the eye, but for the purpose of aiding one in learning the groups, they are all that the student requires.

VARIABLE STARS.

J. A. PARKHURST.

There is a fascination about the observation of variable stars that makes the subject well worth the attention of the amateur. When he has once seen such a star play hide and seek with its neighbors, losing three quarters of its light in two or three hours, or perhaps passing from naked eye visibility down beyond the reach of his telescope of three or four inches aperture in a few months, he will find an interest in the subject which will give a new zest to his star studies.

There is an analogy between variable stars and planets. The planet attracts our attention by changing its place among the stars, the variable star interests us by changing the amount of light which it sends us. There are several hundred of such objects scattered over the sky, differing among themselves in many particulars. Some undergo small changes of light; others send us at their maximum more than a thousand times as much light as at their minimum. Some pass through their cycle of change in a few hours, others require more than a year.

What is the cause of these wonderful phenomena? The question has never been completely answered, though some progress has been made in the past few years. Still the question is mainly unanswered, and further knowledge must be founded upon more and careful observations. Who knows what other important facts may be brought to light when we are able to lift the veil which shrouds this mystery?

I doubt whether there is another field in astronomy which offers the amateurs so good a chance to do work which will materially increase the sum of human knowledge. The veteran astronomer, Dr. B. A. Gould, says of variable stars, "The attractiveness and interest of these objects are great, our knowledge of them is limited, observations of them are comparatively easy, while the field for discovery is evidently very large."

Some of these stars may be observed with the naked eye, as Algol and Mira near its maximum. Many more only require an opera or a field glass, while a three-inch telescope will suffice for observing the maxima of nearly all the known variables and will follow many of them through their whole period.

To quote Professor E. C. Pickering, "Those who have not tried it do not realize the growing interest in a systematic re-

search, and the satisfaction in feeling that by one's own labors the sum of human knowledge has been increased."

I shall try in this series of papers to interest amateurs by giving general descriptions of the various classes of variables and to help those who wish to take up the work by giving methods of observing, recording and reducing the observations, ways of avoiding errors, and, as far as possible, answers to questions which may arise in the course of the work. Aids to identifying the variable will also be given and lists of stars selected suited to the capacity of the instruments which the observers possess. I make no claim to originality in the subject matter but only seek to gather and arrange the information needed by the amateur.

The best classification of variable stars seems to be that of Professor E. C. Pickering of Harvard College Observatory. It is as follows:

"I. Temporary stars. Examples: Tycho Brahe's star (in Cassiopeia) of 1572, new star in Corona 1866, [also the new star in Auriga of 1892].

"II. Stars undergoing great variations in light in periods of several months or years. Examples: o Ceti (Mira) and χ Cygni.

"III. Stars undergoing slight changes according to laws as yet unknown. Examples: α Orionis and α Cassiopeiæ.

"IV. Stars whose light is continually changing, but the changes are repeated with great regularity in a period not exceeding a few days. Examples: β Lyræ and δ Cephei.

"V. Stars which every few days undergo for a few hours a remarkable diminution of light, this phenomenon recurring with great regularity. Examples: β Persei (Algol) and S Cancri."

It will be noticed that there are three points of difference in the above classification:

1st. Length of period.

2nd. Amount of variation.

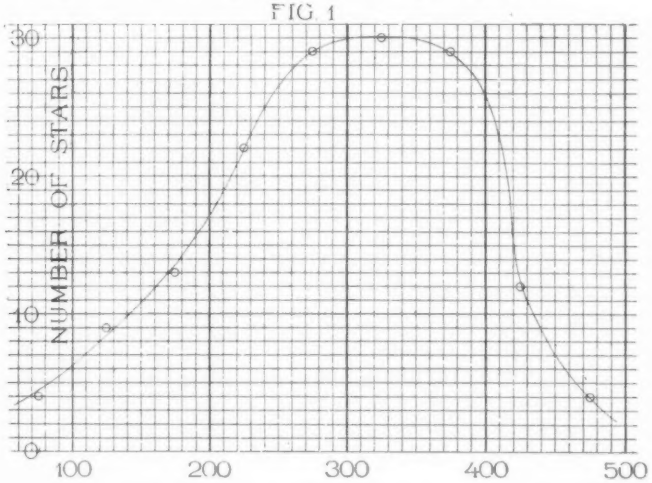
3rd. Character of light curves.

Stars of the class I, temporary stars, are comparatively rare, but often astonishing in the rapidity of their changes. They appear unexpectedly, attain their greatest brilliancy quickly, and fade away slowly. Tycho Brahe's star was the brightest example, being visible at noonday. The new star in Auriga of 1892, has, very naturally, been the most carefully observed, its image being found impressed on photographic plates taken at Harvard College Observatory in December, 1891, about two months before its discovery was announced by Anderson. This star is now

(Oct. 10th, 1893) about the 10th magnitude having remained nearly stationary in light since August, 1892.

No stars of this class have been known to become visible to the naked eye for the second time, so that if they are periodic variables, their periods are very long or very irregular: but there is a wonderful variable, U Geminorum, which seems to form a connecting link between the first and second classes. This star usually is about the 13th magnitude, but occasionally rises in a day or two to the 9th magnitude and then falls more slowly to its original dimness. It repeats these curious antics in irregular periods, averaging about three months. This leads us to think that the "temporary stars" may be doing the same thing on a larger scale and with longer periods. The readers of POPULAR ASTRONOMY will do well to keep watch of these stars. Directions for finding them will be given in a subsequent paper.

FIG. 1



A large part of the variables whose periods are known belong to class II. Dr. S. C. Chandler's Second Catalogue of Variable Stars (*Astronomical Journal*, No. 300), gives 260 known variables. Of this number 155 have periods of more than 50 days, and only 36 less than 50 days, or 81% of the variables of known period belong to class II. The attention of amateurs is especially called to this class of stars, since observations of them are beset with less difficulty than those of classes III, IV and V, while they are more interesting than class I. The length of period of stars of this class varies from 50 days to about 2 years,

but the periods are by no means evenly distributed over this interval, the greatest number having periods of a little less than a year. Fig. 1 will represent this distribution to the eye. The periods were divided into groups of from 50 to 100 days, 100 to 150, etc., and a count was made of the number of stars in each group. The horizontal line represents period in days, the vertical line the proportional number of stars.

The range in brightness between the maxima and minima of these stars differs widely, but on the average they are about five magnitudes brighter at maximum than at minimum. This means that at their brightest they send us 100 times as much light as at their faintest. (What if our Sun should act in that way!) But a much greater range is not uncommon, for instance χ Cygni is at some times 7,000 times as bright as at others.

Classes III and IV have less interest for amateurs on account of the difficulties attending their observation, but class V, the "Algol stars," arrests our attention at once. Algol itself is the best example of the class and a description will be of interest. It is in the constellation Perseus which will be found high in the northeast at 9 o'clock on November evenings. The accompanying sketch, Fig. 2, will enable the beginner to identify it. The stars are of the 2d and 3rd magnitudes. Face the northeast and hold the sketch nearly overhead, with the arrow in the direction of the North Star. The distance between the star marked α and Algol is about 10°, (twice the distance apart of the "Pointers"). A table headed "Minima of Variable Stars of the Algol Type" given in each number of POPULAR ASTRONOMY. From this table we learn that a minimum of Algol will occur about 11 P. M. Nov. 22d, and 8 P. M. Nov. 25th. Let us begin our observations on one of these evenings three or four hours before the time indicated. We will find Algol nearly as bright as α, and much brighter than δ or ρ. As the evening passes on we will find Algol fainter till it finally is less than δ and not much brighter than ρ. As the hour for the minimum passes it will grow brighter till it attains its usual magnitude three or four hours after the indicated time. For the rest of the 2 days and 20 hours its light remains unchanged. No wonder such strange behavior gave it

the name Algol, the demon. It was long ago surmised, and the spectroscope has lately proved that this diminution of light is caused by partial eclipses of the principal star by a close, darker companion, the two revolving around their common center of gravity in 2 days, 20 hours, 49 minutes.

Any amateur who once observes a minimum of Algol will want to do more in this interesting field. To aid in this work I will give in my next paper the means used for designating the variables, the methods of observing and recording the observations, and helps to identify the stars.

Let any reader who wishes to engage in this work communicate with me either directly or through the editor, giving description of the instruments he possesses, and what experience he has had with them, also what star-charts or catalogues he has, and telling whether he can find an object whose right ascension and declination are given.

MARENGO OBSERVATORY, Marengo, Ill.,
1893, Oct. 20.

THE DISTANCES OF THE STARS.

WM. W. PAYNE.

When any person untaught in astronomy is told that the many stars he sees, on any clear and moonless night, are suns, like our own, scattered through space, the next question likely to be asked is, How far are the stars away? Though scholars have thought on this question for centuries, astronomy cannot answer it very well, chiefly because the instruments now in use are too coarse to make the measures needed to determine accurately the very small quantities that enter into the computation of the star distances. This is not so in regard to the dimensions of the solar system; great as they are, the distances of the planets from the Sun are known quite accurately, even in terrestrial units, as miles, and our knowledge extends to much in detail about their sizes, masses, densities and other physical qualities; but when we try to sound the star depths of the universe far beyond the planet realm, with any measuring line now known to science, the task at once becomes enormously great. It will however be profitable to give a brief outline of the efforts that have been put forth to solve it, in order to know how hard the problem is, and to learn what views astronomers now hold in regard to the distances of the stars.

As early as 1610 Tycho Brahe refused to accept the Copernican theory because, with fine instruments, he could not observe an annual change in the relative places of the stars which should appear if that theory was true. He thought his measures were correct to a third of a second of arc, but we now know that his probable error in star places was nearly 200 times greater than he supposed. He reasoned well, but his instruments misled him.

Galileo favored the Copernican theory and suggested the observation of stars near together to decide whether or not relative change of places do occur annually. But Sir William Herschel, whose astronomical work was done between the years 1768 and 1822, was the first to give anything like a rational idea of the extent of the starry universe. The question of its magnitude seemed to be almost constantly in his mind, and it is certain that he tried all means of observation he knew most assiduously to obtain some direct answer to it, but without success. Failing in his favorite way of study, he sought to gain some general idea of the scale on which the universe is built by indirect reasoning. An example of this is, his use of the law of distance as related to stellar brightness. He knew that if any one of the brightest stars were removed from us into space ten times its present distance, it would barely be seen by the naked eye. If the same star were removed 100 times as far away as at first, it could still be seen in a small telescope; but if carried 1,000 times its original distance, then only the great telescopes of the world could reach it, because so far away and so very faint. From such facts as these Herschel reasoned that the brightest stars as a *class* are nearer to us, and that the fainter stars as a *class* are farther away, and that these faint stars may be 1,000 times more distant than the bright ones called the first magnitude. While this asssumption of distance and varying brightness is reasonable for classes of stars, Herschel knew that it would not necessarily hold good when applied to single stars, for, if true, it would follow that all stars must be equal in size, or light-giving power, or both, and such knowledge no one could then affirm. This was as far as indirect reasoning would lead one of the most able and earnest thinkers of his times, and so the problem of individual star distances remained unsolved for many years after his death.

About the year 1839 the distinguished Bessel turned his attention to the problem of stellar distances, by the aid of a new instrument called the heliometer which was designed to measure very small angles. This instrument differs from an ordinary telescope

in having its object-glass cut into halves, and so arranged in the tube that one-half is fixed and the other has motion in a line perpendicular to the axis of the telescope. By this device* and the apparatus connected with it, the observer can measure very accurately the distance between two stars in the same field of view in the telescope. It is to Bessel that we are to give the imperishable honor of first proving unmistakably that the distance of a star is a measurable quantity. The manner in which this result was secured, as well as a description of some other later methods will be given, soon, in an illustrated article concerning distance and parallax.†

We are now more concerned in trying to show just what has been done during the present century in finding the distances of the stars. For this purpose we have copied portions of a drawing which accompanies an excellent article by Mr. A. C. Ranyard "On the Distances of the Fixed Stars," found in *Knowledge* (English) for February, 1890. We have omitted from the plate (which is the frontispiece to this number), the names of the observers, dates, and parallaxes obtained by each, and reduced the original about one-half, our object being to show, at a glance, nearly all the stars whose parallaxes have been studied during the present century, and to indicate their distances from the Sun and the degree of certainty of present knowledge concerning the same.

Our Sun is supposed to be in the center of the figure. One-tenth of the distance from the center to the circumference in any direction represents the distance of stars whose parallax is one second of arc; two-tenths, stars having a parallax of half a second, and so on. For stars on the circumference the distance would correspond to a parallax of one-tenth of a second, and, in some cases, to what is called *negative* parallax, which is about equivalent to saying that the observer's work in such cases was unsatisfactory. If a star has a parallax of one second of arc (none known is so great as that) its distance is 63,000 times as great as that of the Earth from the Sun, or nearly 6 millions of miles. It would take light traveling at the rate of 186,000 miles per second 3.26 years to reach us from a star at such a distance. A convenient unit of measure for star distances is the light-year, or the distance that light travels in one year, and this mode of estimate is now commonly used. From statements already made, it is easy for any one to find the distance of any star in light-years on the plate, by the following simple formula:

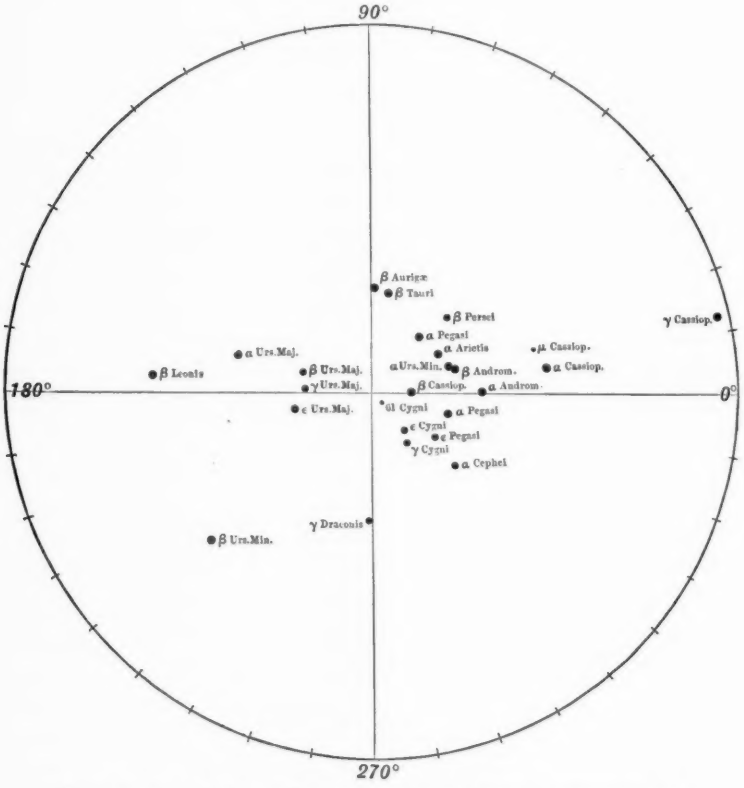
* An illustration of the divided glass, and a description of the way it is used may be found in *Young's General Astronomy*, page 677.

† *Young's General Astronomy*, page 461.

$$\text{Light-years} = \frac{3.26}{p''},$$

p meaning the parallax in seconds of arc. If the star is on the circumference of the circle,

$$\text{Light-years} = \frac{3.26}{0''.1} = 32.6.$$



DISTANCES OF 29 STARS OBTAINED BY THE AID OF PHOTOGRAPHY BY PROFESSOR PRITCHARD.

The following table will be plain if we say the first column is tenths of distance from the center to the circumference, second column is parallax corresponding to adjacent tenths of radius, and last column is light-years:

Tenths.	p''	L.-Y.	Tenths.	p''	L.-Y.
.1	1.00	3.26	.6	0.16	19.56
.2	0.50	6.52	.7	0.14	22.82
.3	0.33	9.78	.8	0.12	26.08
.4	0.25	13.04	.9	0.11	29.34
.5	0.20	16.30	1.0	0.10	32.60

If this table were extended to include faint stars, the remote ones are probably so far away that the journey of their light in reaching us would require many thousands of years.

Another impressive feature of the plate, of a different kind, is the *uncertainty* of our knowledge of the distances of the stars represented. This is shown by the varying lengths of the radial lines drawn through the stars. These lines are intended to connect points which represent respectively the different distances found by different observers. The places given to the stars on the radial lines are the most probable mean values of all the observations.*

The uncertainty in value in these results arises in part from the fact that observers are trying to measure quantities smaller than they can see. Professor Young's illustration is an apt one. Suppose Polaris has a parallax of 0″.08, with an error of observation amounting to $\frac{1}{50}$ of a second (which is a favorable assumption for the observer), that error would be one-fourth of the whole value, and to determine it would be like trying to measure $\frac{1}{16}$ of an inch at a distance of ten miles. Such an attempt by any methods of measurement now known to us would be next to impossible. This point will be enlarged upon in the paper to follow already referred to.

The accompanying figure is an illustration of the distance of 29 stars obtained by the aid of photography by the late Rev. Chas. Pritchard at Oxford University Observatory, England, during the years 1887—1890, and published in the *Vierteljahrsschrift der Astronomischen Gesellschaft* (German), 1893, p. 117. This is some of the latest published work we know of by this method. The figure is on the same plan as that of the frontispiece and the distances of its stars may be determined in the same way.

JUPITER AT OPPOSITION. A NAKED-EYE STUDY.

ELIZA A. BOWEN.

The opposition of Jupiter or Saturn gives an opportunity to make our acquaintance with a superior planet's motions a genuine study of nature. It is important to teachers to know how this may be done, but also to all persons who have only a book knowledge of astronomy.

* For the right ascension, declination, parallax, dates, instruments, observers, etc., of all these stars, amounting in all to over 70, see a useful table by Mr. Herbert Sadler, *Knowledge*, February, 1890, page 63.

The opposition of Jupiter comes on November 18, 1893, and I propose in this paper to give a plan for observation study.

The "opposition" of Jupiter means that Jupiter and the Sun are seen by us against opposite points of the heavens, points 180° apart on the celestial sphere, and the proper object of the observer is first to have as much testimony of his own eyes as is possible, to the truth of this statement. Both the Earth and Jupiter are moving, and the exact instant of opposition does not come at sunset, but the movement is so slow that the situation is little altered for a day or two to an observer without measuring instruments. At sunset we can see the point of the celestial horizon 180° from the Sun, and Jupiter is just above it, and very soon, as light lessens, we see Jupiter against, or in, the constellation Taurus.

The observer should answer the following questions:

Did the Sun set north or south of the west point of the horizon? How many degrees separate the east and west points of the horizon? If the Sun has set south of the west point, would a point 180° from the Sun at sunset be north or south of the east point of the horizon? Is Jupiter north of the east point? Does what you see go to confirm or to disprove the statement that Jupiter is 180° from the Sun? Do the three bodies, the Sun, the Earth and Jupiter appear to be in a straight line? Which is in the middle? Which is nearer to the Sun, the Earth, or Jupiter?

The Earth is not exactly on a straight line extending through the centres of the Sun and Jupiter, but is only so near it that we say practically that the Earth at opposition crosses the line between Jupiter and the Sun. A line through the centres of Earth and Sun would, if extended, pass through the circle of the ecliptic on the celestial sphere. It is easy to see that Jupiter is not on that circle, but very near it.

At midnight the observer can again test the statement that the Earth is crossing a line between the centres of Jupiter and the Sun. He should answer these questions:

Is the Sun now north or south of the Earth's equator? When the Sun is on the meridian below the horizon, would a point of that meridian 180° from the Sun be north or south of the Earth's equator and the equator of the heavens? Does Jupiter appear to be in that position?

Our knowledge of the chief motion of Jupiter is based on seeing the planet when we cross the line between it and the Sun. I will show how it leads us to certain conclusions. What I say will be worthless unless it is followed step by step by observation.

It is now desirable for the observer to go out again at sunset, and as the situation changes so slowly, the evening of November 19 will do.

There appears to be a great sphere or dome above us and the Sun seems to be on one side of it, but this is merely the result of perspective, and we must try to get rid of this idea. We must think of the Sun as being the centre of the heavens (for us). The stars on all sides of the Sun are at an immense distance from him.

At every sunset, the path which the Earth has traveled for the previous six months in revolving round the Sun, lies in the space above us. In November, the Sun at sunset lies southwest of us, and if we imagine a line beginning far southwest of the Sun and coming in a great semi-circle northwest of the Sun and passing down through the centre of the Earth, it would represent, with sufficient accuracy for our purpose, the path which the Earth's centre has traveled for six months. Last May, the Earth was on the southwestern end of that semi-circle, and during last June, July, August, September, October, she has traveled northeast round that path, and now she has brought us to the northeast end of the semi-circle.

This path could be more definitely represented if we could see the stars at sunset, but they are there. Scorpio is southwest of the Sun on the celestial horizon, but far beyond the Sun. Coming northeast, there are Sagittarius, Capricornus, Aquarius, Pisces, Aries, and finally Taurus, which lies northeast of us.

The student must now stop until dark, and just as soon as the stars come out, look at these constellations. Taurus is now above, not on, the horizon, and the Sun and Scorpio are below the western horizon but the change is not great. The line across the base of that semi-circle is, on the west, inclined a very little downward, but you can imagine it.

Let us add that every year, from May to November, the Earth's centre travels round this semi-circle. The corresponding semi-circle, which is the Earth's path from November to May, lies below the horizon at sunset.

If the reader has this semi-circle round the Sun well fixed in his imagination when, just at dark, he looks at Jupiter and the stars, he is prepared to understand some facts that I will describe, seen by myself and other eyewitnessess when the Earth was traveling eastward on that path in the years 1888, 1889, 1890, 1891, 1892.

In May, 1888, the Earth was on the other side of the Sun, beginning her six months' journey round that semi-circle, and on May 22, she crossed the line joining Jupiter and the Sun, and I and all other eyewitnesses saw Jupiter in Scorpio, just as you now see the planet in Taurus. Jupiter was then as now on our right when we face north, for we have unconsciously been turned upside down since then, in consequence of the Earth's revolution round the Sun. After crossing that line, the Earth continued her journey round the semi-circle and, finally, round the other semi-circle now below the horizon.

Finally in May, 1889, she again began to travel round the semi-circle now above us and on June 25, 1889, the Earth again crossed a line extending from Jupiter to the Sun and I and the other eyewitnesses saw Jupiter in the constellation Sagittarius. Then the Earth continued her journey round the Sun.

Again in May, 1890, she entered on the semi-circle above us and on July 30, 1890, she again crossed a line extending from Jupiter to the Sun. I and the other eyewitnesses saw Jupiter near the western boundary of Aquarius. After that the Earth made another revolution round the Sun on these semi-circles.

Next, in May, 1891, the Earth began her journey on the semi-circle above us and as she traveled round, on September 5, she crossed a line joining the centres of Jupiter and the Sun. We then saw Jupiter in Pisces. After that, the Earth completed her revolution round the Sun.

In May, 1892, the Earth again began her path round the semi-circle above us, and on October 12, 1892, she crossed a line extending from Jupiter to the Sun. I and other eyewitnesses saw Jupiter in or against Aries. Then the Earth finished her revolution.

Finally, last May, the Earth began her last journey round the semi-circle (until 1894) and as you know, and can partly see for yourself, on November 18, the Earth again crosses a line extending from Jupiter to the Sun. This is six years and nearly six months since I saw Jupiter in Scorpio at the planet's opposition of 1888. This sixth revolution of the Earth will not be completed until next May.*

It is only when we are crossing the line between Jupiter and the Sun, that we see the planet where it would be seen by an observer at the Sun. Point in succession to all the constellations named, and answer the following questions:

If Jupiter was seen successively against, or in, those star groups, would a motion of Jupiter account for those changes of position? Does Jupiter move on a curved or a straight line? Does Jupiter move eastward or westward? Do Jupiter and the Earth move in the same or in contrary directions? Around what centre does Jupiter revolve? Is the path or orbit of Jupiter within or without the Earth's orbit? How long does it take the Earth to travel round this semi-circle? How long has it taken Jupiter? The Earth on November 18 is crossing a line extending from the Sun through Jupiter to Taurus, can you (roughly) estimate how long it will take Jupiter to revolve round the Sun and again reach the line it is on at the precise moment of opposition? This is a sidereal revolution of Jupiter. What fraction of a sidereal revolution has Jupiter made since May 22, 1888? How many oppositions have been seen since? From one opposition to the next is called a synodical period. How many synodical periods (or revolutions) have taken place while Jupiter has revolved half way round the Sun?

* Perhaps some teachers will think that a diagram would aid in making this clear. For a teacher who gives an oral lesson on it, pointing to the constellations and revolving the finger in a circle, there will be no need whatever of a diagram to make it clear. If students see a diagram first they will always, whenever they think of the subject, see with their "mind's eye" a diagram and not objects in nature.

Of course the Earth's path is an ellipse, not a circle; but it is an ellipse which cannot be distinguished from a circle except by accurate measurement. The imagination of ordinary students more easily represents a semi-circle in nature than half of an ellipse.

TO BE CONTINUED.

THE FACE OF THE SKY.

CHARLOTTE R. WILLARD.

The present season affords sights of rare beauty to the naked-eye observer of the heavens. As soon as twilight comes on Venus is seen in the west, while Jupiter is well up in the east; because of their surpassing brilliancy these two planets are unmistakable. To one unfamiliar with the heavens, this is perhaps the best time of year for beginning study, as the evenings are now long and the most striking constellations of the northern hemisphere pass before us between the hours of seven and ten. Much can be gained by any one who without chart or guide will observe the stars and their varying positions during the hours named—perhaps such unaided work is the best possible preparation for the later use of charts and other helps.

We will make a brief statement of the heavens as they will appear in our latitude (44° N.) on the evening of December first.

Facing the north the Big Dipper is seen with its base no longer parallel to the horizon, but having moved so far in its progress around the pole that the extreme star in the handle is now near the horizon. Cassiopeia is seen just crossing the meridian and only fifteen degrees from the zenith; while the Little Dipper lies between these two constellations and to the west, having its bowl perpendicular to the horizon. Two first magnitude stars are visible in the west; the more northern of these is Vega which locates for us Lyra; the other star is Altair (α Aquilæ). Southeast of Vega is a noticeable group of four stars which mark the constellation Cygnus: these stars are so situated that they make a nearly isosceles triangle, having three stars in the base; the central star of the base (γ Cygni) is about twenty-five degrees from Vega; if the line from the star at the vertex (α) through γ be continued for about twenty degrees, β is found; this star marks the head of Cygnus. High in the heavens is the great Square of Pegasus. The Great Nebula of Andromeda is just past the meridian and very near the zenith. To the east we find the familiar group Pleiades followed by the Hyades (a V-shaped group of five stars including the red first magnitude star Aldebaran). Still farther to the east and only a little above the horizon is Orion; much farther north and rising at the same time with Orion is the zodiac constellation Gemini clearly marked by the two bright stars Castor and Pollux; Castor rises first, the two are about four and a half degrees apart. The first magnitude star Capella makes a nearly equilateral triangle with Pollux and Betelgeuse (the most northern first magnitude star of Orion).

The evening of December first will be free from moon light and if perfectly clear will show much of interest in the Milky Way, although the presence of Jupiter's light will be a disadvantage. At first glance there may seem to be little to notice in this cloud-like path across the sky; but when the eye becomes accustomed to the dim light, marvelous changes are wrought in its appearance. Its apparent extent increases as one is able to detect the fainter parts; the study of its position on the celestial sphere becomes most interesting; a division is noticed from Cygnus down to the western horizon; a question arises as to the relative number of naked-eye stars in the Milky Way and in the rest of the heavens; the parts are seen to differ much in brightness, possibly suggesting that we are nearer to some parts than to others; details at first unsuspected are seen as the eye becomes more sensitive and can detect "the fringes, rifts, vacuities, rings, sprays and streams of stars" in countless variety; the dark, seemingly starless vacuities excite wonder and conjecture; the borderland of the Milky Way suggests much.

Probably the best drawings ever made of the Milky Way as a whole, are those of Dr. Boeddicker. In preparing his maps Dr. Boeddicker took his observations while lying on the ground under the open heavens; after careful study of a section, the drawings were made from memory.

An opera-glass adds greatly to the interest of Milky Way study: it resolves much that is cloud-like to the naked eye, into multitudes of clearly shining stars.

We will briefly state some of the conclusions which have been reached from a study of the Milky Way.

It covers more than one-tenth of the visible heavens.

The central line of the Milky Way differs very little from a great circle of the celestial sphere—a fact which leads to the conclusion that whatever this great

band may be, whatever its wonderful structure and relation to the rest of the universe, our Earth must be in or close to its central plane.

The stars visible to the naked eye are more numerous on the Milky Way than elsewhere. "The Milky Way is made up almost wholly of small stars from the eighth magnitude down. It contains also a large number of star clusters but very few true nebulæ."—Professor C. A. Young. Professor Pickering's spectroscopic work seems to indicate that the Milky Way forms a system separate from the rest of the siderial Universe.

"There can at least be very little doubt that galactic stars are in general fully the equal of our Sun in real lustre."—Agnes Clerke.

"What is unmistakable is that the entire formation whether single or compound, is no isolated phenomenon. All the contents of the firmament are arranged with reference to it. It is a large part of a larger scheme exceeding the compass of finite minds to grasp in its entirety."—Agnes Clerke.

PLANET NOTES FOR DECEMBER.

H. C. WILSON.

Mercury will be morning planet during December and will be visible to the unaided eye during the middle of the month. One must look toward the southeast about an hour before sunrise in order to see it. Mercury will be at greatest elongation, west from the Sun 21° 23′, Dec. 14 at noon.

Venus will be evening planet during December setting in the southwest between seven and eight P. M. Although so brilliant to the eye it will not, on account of its low altitude, be in good position for telescopic observation in northern latitudes. Venus will be at greatest elongation, east from the Sun 47° 29′, Dec. 6 at $3^h\ 36^m$ P. M. In the southern hemisphere this will be a very favorable opportunity to study the surface markings of Venus and it is to be hoped that Professor W. H. Pickering and his assistants at Arequipa will be able to add much to our knowledge of this subject and of the rotation of the planet.

Mars will be morning planet, but is getting farther south all the time so that its position will be unfavorable for northern observers. In the southern hemisphere the conditions will be much better. There will be quite a close conjunction of *Mars* and *Uranus* Dec. 6 at $4^h\ 09^m$ central time, when the former will be only 8′ north of the latter. Observers in Australia and Japan should be able to see the two planets in the same field of view of the telescope. The ruddy color of Mars and the green hue of Uranus will present a striking contrast. Eighteen hours later Mars will pass close to the wide double star α Libræ, the components of which Webb puts as third magnitude, pale yellow, and sixth magnitude light grey. Mars will pass 11′ north of the brighter star.

Jupiter, having but just passed opposition, will be in excellent position for observation during December. We have had a few good views of the planet this year when much of fine detail was seen upon the surface, notably a large number of very small dark red spots. The "great red spot" was seen by us with the 16-inch telescope on the night of Oct. 31. Its center was on the central meridian of Jupiter at $11^h\ 31^m$, central time, as near as we could estimate. This time agrees closely with that predicted by Mr. Marth. The spot was seen without difficulty although the color was quite faint. The color was exactly the same as that of the belt just to the south of it and the two objects merged into one another without the slightest change in intensity of color. The outline of the spot seems to be the same as in past years, except as stated above, that its southern edge is merged into the belt. There seemed to be two white clouds over the central portions of the spot, the following of the two being the larger. We give among the tables in this number a portion of Marth's ephemeris of the spot so that our readers may know just when it may be seen. The apparent diameter of Jupiter during December diminishes from 46″ to 44″. His brilliancy will be greater than that of any other object in the evening sky, excepting the Moon, so that none can mistake him. His course is slowly westward in Taurus.

Saturn will be visible in the morning, but at a low altitude, so that for northern observers there will be no satisfactory observations. Saturn is in the constellation Virgo just a little north and east of the star Spica. The planet is the

brighter of the two. The rings of Saturn are pretty well opened now, the angle of their plane to the line of sight being now about 12°, and increasing to 14° at the end of December. Saturn and the Moon will be in conjunction Dec. 3 at 3^h 20^m P. M. and Dec. 31 at 1^h 41^m A. M. Saturn will be about 3° north of the Moon in both instances.

Uranus is in Libra very close to the star α, referred to above in the note on Mars. At 5^h 32^m on the morning of Dec. 16, Uranus will be in conjunction with the star, only 3′ north. The conjunction with Mars has already been mentioned.

Neptune will be at opposition Dec. 3 and therefore in best position for observation during December. Its motion during the month will be 53′ west and 6′ south. The position Dec. 1 will be one third of the distance on a straight line from ι to ε Tauri. A photograph taken at Goodsell Observatory, Oct. 18, shows no star as bright as Neptune within 1° of this position.

Planet Tables for December.

[The times given are local time for Northfield. To obtain Standard Times for Places in approximately the same latitude, add the difference between Standard and Local Time if west of the Standard Meridian or subtract if east].

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
		MERCURY.			
Dec. 5	15 40.2	− 16 47	5 47 A. M.	10 41.3 A. M.	3 36 P. M.
15	16 04.5	− 18 38	5 40 "	10 26.3 "	3 13 "
25	16 56.8	− 21 50	6 08 "	10 39.1 "	3 10 "
		VENUS			
Dec. 5	20 16.5	− 22 24	10 48 A. M.	3 17.0 P. M.	7 46 P. M.
15	20 56.8	− 19 20	10 35 "	3 17.7 "	8 01 "
25	21 31.5	− 15 47	10 14 "	3 13.0 "	8 12 "
		MARS.			
Dec. 5	14 39.7	− 15 00	4 38 A. M.	9 41.0 A. M.	2 44 P. M.
15	15 06.1	− 17 01	4 34 "	9 28.2 "	2 22 "
25	15 33.4	− 18 50	4 31 "	9 16.1 "	2 01 "
		JUPITER.			
Dec. 5	3 27.8	+ 17 46	3 10 P. M.	10 27.0 P. M.	5 44 A. M.
15	3 23 4	+ 17 32	2 27 "	9 43.3 "	4 59 "
25	3 19.9	+ 17 22	1 45 "	9 00.6 "	4 16 "
		SATURN.			
Dec. 5	13 25.9	− 6 30	2 50 A. M.	8 27.4 A. M.	2 05 P. M.
15	13 29.1	− 6 47	2 15 "	7 51.4 "	1 28 "
25	13 31.8	− 7 11	1 39 "	7 14.8 "	12 50 "
		URANUS.			
Dec. 5	14 42.7	− 15 22	4 43 A. M.	9 44.1 A. M.	2 45 P M.
15	14 44.8	− 15 32	4 07 "	9 06.8 "	2 07 "
25	14 46.7	− 15 40	3 30 "	8 29.5 "	1 29 "
		NEPTUNE.			
Dec. 5	4 43.2	+ 20 42	4 11 P. M.	11 42.2 P. M.	7 13 A. M.
15	4 42.0	+ 20 40	3 31 "	11 01.7 "	6 32 "
25	4 40.9	+ 20 38	2 51 "	10 21.3 "	5 52 "
		THE SUN.			
Dec. 5	16 50.1	− 22 29	7 23 A. M.	11 51.0 A. M.	4 19 P. M.
15	17 34.1	− 23 19	7 32 "	11 55.6 "	4 20 "
25	18 18.5	− 23 23	7 37 "	12 00.6 "	4 24 "

Phases and Aspects of the Moon.

	Central Time. d h m
New Moon	Dec. 8 1 40 A. M.
Apogee	" 9 5 24 A. M.
First Quarter	" 16 4 21 A. M.
Perigee	" 22 9 18 P. M.
Full Moon	" 22 10 37 P. M.
Last Quarter	" 29 5 18 P. M.

Phenomena of Jupiter's Satellites.

	h	m					h	m			
Dec.	2	1	48	A. M.	III	Oc. Dis.	Dec. 16	3	18	P. M.	II	Ec. Re.
		4	46	"	III	Ec. Re.		3	35	"	I	Tr. Eg.
	4	1	34	"	II	Tr. In.		4	18	"	I	Sh. Eg.
		2	20	"	II	Sh. In.	19	10	26	"	III	Tr. In.
		3	51	"	II	Tr. Eg.		11	53	"	III	Tr. Eg.
		4	20	"	I	Tr. In.	20	12	46	A. M.	II	Oc. Dis.
		4	41	"	II	Sh. Eg.		1	18	"	III	Sh. In.
		4	44	"	I	Sh. In.		2	16	"	I	Tr. In.
	5	1	31	"	I	Oc. Dis.		3	03	"	I	Sh. In.
		4	07	"	I	Ec. Re.		3	08	"	III	Sh. Eg.
		3	37	P. M.	III	Tr. In.		11	29	P. M.	I	Oc. Dis.
		5	06	"	III	Tr. Eg.	21	2	27	A. M.	I	Ec. Re.
		5	17	"	III	Sh. In.		7	21	P. M.	II	Tr. In.
		7	06	"	III	Sh. Eg.		8	43	"	I	Tr. In.
		8	15	"	II	Oc. Dis.		8	56	"	II	Sh. In.
		10	46	"	I	Tr. In.		9	31	"	I	Sh. In.
		11	13	"	I	Sh. In.		9	41	"	II	Tr. Eg.
		11	25	"	II	Ec. Re.		10	55	"	I	Tr. Eg.
	6	12	57	A. M.	I	Tr. Eg.		11	17	"	II	Sh. Eg.
		1	25	"	I	Sh. Eg.		11	44	"	I	Sh. Eg.
		7	57	P. M.	I	Oc. Dis.	22	5	56	"	I	Oc. Dis.
		10	36	"	I	Ec. Re.		8	56	"	I	Ec. Re.
	7	3	39	"	II	Sh. In.	23	1	56	"	II	Oc. Dis.
		5	00	"	II	Tr. Eg.		3	10	"	I	Tr. In.
		5	12	"	I	Tr. In.		3	15	"	III	Ec. Dis.
		5	41	"	I	Sh. In.		4	00	"	I	Sh. In.
		6	00	"	II	Sh. Eg.		4	52	"	III	Ec. Re.
		7	23	"	I	Tr. Eg.		5	22	"	I	Tr. Eg.
		7	54	"	I	Sh. Eg.		5	54	"	II	Ec. Re.
	8	5	05	"	I	Ec. Re.		6	13	"	I	Sh. Eg.
	11	3	51	A. M.	II	Tr. In.	24	3	25	"	I	Ec. Re.
		4	58	"	II	Sh. In.	27	1	40	A. M.	III	Tr. In.
	12	3	16	"	I	Oc. Dis.	28	1	16	"	I	Oc. Dis.
		6	55	P. M.	III	Tr. In.		9	43	P. M.	II	Tr. In.
		8	28	"	III	Tr. Eg.		10	30	"	I	Tr. In.
		9	18	"	III	Sh. In.		11	26	"	I	Sh. In.
		10	30	"	II	Oc. Dis.		11	35	"	II	Sh. In.
		11	07	"	III	Sh. Eg.	29	12	03	A. M.	II	Tr. In.
	13	12	31	A. M.	I	Tr. In.		12	42	"	I	Tr. Eg.
		1	08	"	I	Sh. In.		1	39	"	I	Sh. Eg.
		2	00	"	II	Ec. Re.		1	56	"	II	Sh. Eg.
		2	42	"	I	Tr. Eg.		7	43	P. M.	I	Oc. Dis.
		3	20	"	I	Sh. Eg.		10	52	"	I	Ec. Re.
		9	42	P. M.	I	Oc. Dis.	30	3	15	"	III	Oc. Dis.
	14	12	31	A. M.	I	Ec. Re.		4	16	"	II	Oc. Dis.
		5	00	P. M.	II	Tr. In.		4	57	"	I	Tr. In.
		6	18	"	II	Sh. In.		5	00	"	III	Oc. Re.
		6	57	"	I	Tr. In.		5	55	"	I	Sh. In.
		7	18	"	II	Tr. Eg.		7	09	"	I	Tr. Eg.
		7	37	"	I	Sh. In.		7	17	"	III	Ec. Dis.
		8	39	"	II	Sh. Eg.		8	08	"	I	Sh. Eg.
		9	09	"	I	Tr. Eg.		8	29	"	II	Ec. Re.
		9	49	"	I	Sh. Eg.		8	54	"	III	Ec. Re.
	15	4	09	"	I	Oc. Dis.	31	2	11	"	I	Oc. Dis.
		7	00	"	I	Ec. Re.		5	20	"	I	Ec. Re.

In. denotes ingress; Eg. egress; Dis., disappearance; Re., reappearance; Ec., eclipse; Oc., occultation; Tr., transit of the satellite; Sh., transit of the shadow. Only the phenomena visible in the United States are given. The times are Central Standard.

☞ **E. E. Barnard** of Lick Observatory has contributed an illustrated article concerning the new Brook's comet. It comes to hand too late for this issue. Something good is promised about the freaks of the tail of this comet learned from the photographs of it taken at the Lick Observatory.

Approximate Central Standard Times when the Great Red Spot will cross the Central Meridian of Jupiter.

		h	m										
Nov.	15	8	58	P. M.	Dec.	2	12	06	A. M.	Dec.	17	5	20 "
	16	4	49	"		2	7	57	P. M.		18	3	15 A. M.
	17	2	44	A. M.		3	5	52	A. M.		18	11	07 P. M.
	17	10	36	"		3	3	48	P. M.		19	6	58 "
	18	6	27	P. M.		4	1	44	A. M.		20	4	53 A. M.
	19	4	22	A. M.		4	9	35	P. M.		21	12	45 "
	20	12	14	"		5	5	26	"		21	8	36 P. M.
	20	10	05	P. M.		6	3	21	A. M.		22	4	28 "
	21	3	56	"		6	11	13	P. M.		23	2	24 A. M.
	22	1	52	A. M.		7	7	05	"		23	10	15 P. M.
	22	9	43	P. M.		8	5	00	A. M.		24	6	06 "
	23	5	34	"		9	12	51	"		25	4	01 A. M.
	24	3	29	A. M.		9	8	43	P. M.		25	11	53 P. M.
	24	11	21	P. M.		10	4	34	"		26	7	44 "
	25	7	12	"		11	2	30	A. M.		27	5	39 A. M.
	26	5	07	A. M.		11	10	21	P. M.		27	3	36 P. M.
	26	3	03	P. M.		12	6	02	"		28	1	32 A. M.
	27	12	59	A. M.		13	3	57	A. M.		28	9	23 P. M.
	27	8	50	P. M.		13	11	59	P. M.		29	5	14 "
	28	4	41	"		14	7	50	"		30	3	09 A. M.
	29	2	31	A. M.		15	5	45	A. M.		30	11	01 P. M.
	29	10	28	P. M.		15	3	42	P. M.		31	6	53 "
	30	6	19	"		16	1	37	A. M.				
Dec.	1	4	09	A. M.		16	9	29	P. M.				

Configuration of Jupiter's Satellites, at 9:30 p. m. Central Time for an Inverting Telescope.

Dec.										Dec.										Dec.									
1			2	3	○	1	4			12			3	2	○	1	4			23			4	1	○	2	3		
2			1	4	○	2	3			13			3	1	○	2	4			24				4	○	1	2	3	
3				4	○	2	1	3		14		3	2	1	○	4				25		4	2	1	○	3			
4		4	2	1	○	3				15			2	3	○	1	4			26			4	2	○	3	1		
5			4	3	○	1	●			16				1	○	2	3	4		27			3	1	○	4	2		
6			4	3	○	2	●			17					○	2	1	4	3	28		2	3	○	1	4			
7	4	3	2	1	○					18			2	1	○	4	3			29		3	2	○	4	●			
8		4	2	3	○	1				19			4	2	○	1	2			30			1	○	2	3	4		
9			4	1	○	2	3			20		4	3	1	○	2				31				○	1	2	3	4	
10				●	○	2	1	3		21			4	3	○	2	2												
11			2	1	○	3	4			22		4	2	3	○	1													

Elongations of the Satellites of Saturn.

(The western elongations will be found approximately half way between the eastern and other positions may be easily interpolated.)

MIMAS					MIMAS CONT.					ENCELADUS				
		h					h					h		
Dec.	9	4.9	A. M.	E	Dec.	21	10.9	A. M.	E	Dec.	15	6.6	A. M.	E
	10	3.5	"	E		22	9.5	"	E		16	3.5	P. M.	E
	11	2.1	"	E		23	8.1	"	E		18	12.4	A. M.	E
	12	12.7	"	E		24	6.8	"	E		19	9.3	"	E
	12	11.3	P. M.	E		25	5.5	"	E		20	6.2	P. M.	E
	13	9 9	"	E		26	4.1	"	E		22	3.1	A. M.	E
	14	8.6	"	E		27	2.7	"	E		23	11.9	"	E
	15	7.3	"	E		28	1.3	"	E		24	8.8	P. M.	E
	16	5.9	"	E		28	11.9	P. M.	E		26	5.7	A. M.	E
	17	4.5	"	E		29	10.5	"	E		27	2.6	P. M.	E
	18	3.1	"	E		30	9.1	"	E		28	11.5	"	E
	19	1.7	"	E		31	7.8	"	E		30	8.4	A. M.	E
	20	12.3	"	E							31	5.3	P. M.	E

TETHYS

	h		
Dec. 13	5.3	A. M.	E
15	2.6	"	E
16	11.9	P. M.	E
18	9.3	"	E
20	6.6	"	E
22	3.9	"	E
24	1.2	"	E
26	10.5	A. M.	E
28	7.8	"	E
30	5.1	"	E

DIONE

Dec. 14	8.8	A. M.	E
17	2.5	"	E

DIONE CONT.

Dec. 19	8.2	P. M.	E
22	1.9	"	E
25	7.6	A. M.	E
28	1.3	"	E
30	7.0	P. M.	E

RHEA

Dec. 6	1.8	P. M.	E
11	2.4	A. M.	E
15	2.9	P. M.	E
20	3.4	A. M.	E
24	3.9	P. M.	E
29	4.4	A. M.	E

TITAN

Dec. 14	6.9	P. M.	W
22	4.3	"	E
30	6.1	"	W

HYPERION

Dec. 15	8.4	P. M.	E
27	2.2	"	W

JAPETUS

Dec. 10	6.2	A. M.	W
30	4.5	P. M.	S

Minima of the Variable Stars of the Algol Type.

[Given to the nearest hour in Central Standard Time.]

U CEPHEI.

R. A.....$0^h\ 52^m\ 32^s$
Decl.....$+81°\ 17'$
Period.....$2d\ 11^h 50^m$

Dec. 6	3	A. M.
11	2	"
16	2	"
21	2	"
26	1	"
31	1	"

ALGOL.

R. A.....$3^h\ 1^m\ 1^s$
Decl.....$+40°\ 32'$
Period.....$2d\ 20^h 49^m$

Dec. 10	4	A. M.
13	1	"
15	9	P. M.
18	6	"
30	6	A. M.

λ TAURI.

R. A.....$3^h\ 54^m\ 35^s$
Decl.....$+12°\ 11'$
Period.....$3d\ 22^h 52^m$

Dec. 4	4	P. M.
8	3	P. M.

R. CANIS MAJORIS.

R. A.....$7^h\ 14^m\ 30^s$
Decl.....$-16°\ 11'$
Period.....$1d\ 3^h\ 16^m$

Dec. 6	5	P. M.
7	8	"
8	11	"
10	3	A. M.
11	6	"
14	4	P. M.
15	8	"
16	11	"
18	2	A. M.
19	6	"

R. CANIS MAJ. CONT.

Dec. 23	6	P. M.
24	10	"
26	1	A. M.
27	4	"

S CANCRI.

R. A.....$8^h\ 37^m\ 39^s$
Decl.....$+19°\ 26'$
Period.....$9d\ 11^h 38^m$

Dec. 1	5	P. M.
10	5	A. M.
19	5	P. M.
29	4	A. M.

S ANTLIÆ.

R. A.....$9^h\ 27^m\ 30^s$
Decl.....$-28°\ 09'$
Period.....$0d\ 7^h\ 47^m$

Dec. 1	10	P. M.
2	6	A. M.
	9	P. M.
3	5	A. M.
	9	P. M.
4	5	A. M.
	8	P. M.
5	4	A. M.
	7	P. M.
6	3	A. M.
	6	P. M.
7	3	A. M.
	6	P. M.
8	2	A. M.
9	1	"
	midn.	
10	midn.	
11	11	P. M.
12	10	"
13	6	A. M.
	9	P. M.
14	6	A. M.

S. ANTLIÆ CONT.

Dec. 14	9	P. M.
15	5	A. M.
	8	P. M.
16	4	A. M.
	7	P. M.
17	4	A. M.
	7	P. M.
18	3	A. M
	6	P. M.
19	3	A. M.
	6	P. M.
20	2	A. M.
21	1	A. M.
22	1	A. M.
	midn.	
23	midn.	
24	11	P. M.
25	10	"
26	6	A. M.
	9	P. M.
27	6	A. M.
	8	P. M.
28	5	A. M.
	8	P. M.
29	4	A. M.
	7	P. M.
30	3	A. M.
	6	P. M.
31	3	A. M.
	6	P. M.

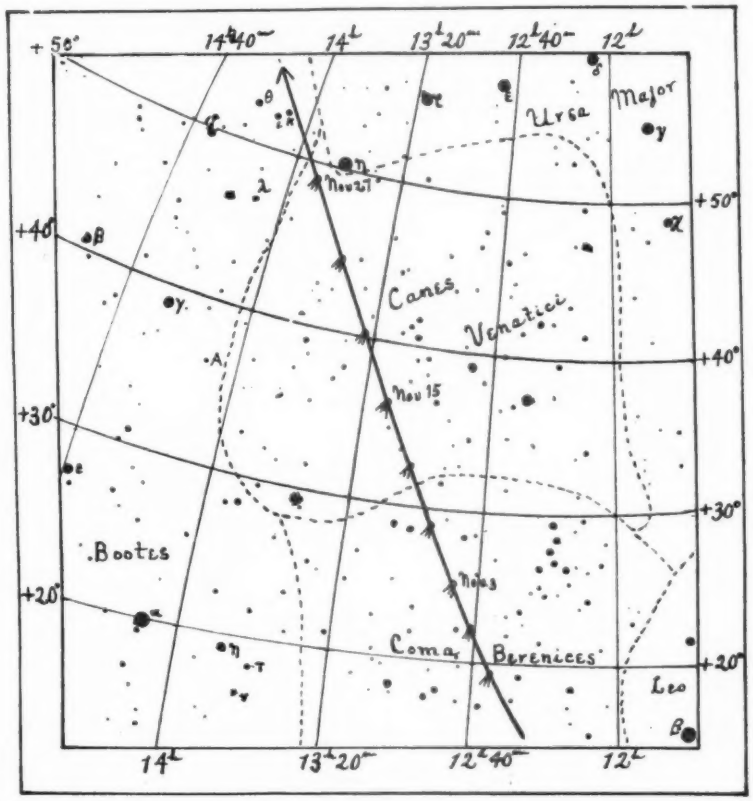
U. CORONÆ.

R. A.....$15^h\ 13^m\ 43^s$
Decl.....$+32°\ 03'$
Period.....$3d\ 10^h\ 51^m$

Dec. 11	5	A. M.
18	3	"
24	midn.	

Occultations Visible at Washington.

Date 1893.	Star's Name.	Magnitude.	IMMERSION Washington M. T. h m	IMMERSION Angle f'm N pt. °	EMERSION Washington M. T. h m	EMERSION Angle f'm N pt. °	Duration. h m
Dec. 10	B.A.C. 6628	5.9	5 21	110	6 25	211	1 04
17	ζ Piscium	4.8	13 18	99	14 04	213	0 56
19	40 Arietis	6.3	6 32	359	7 08	294	0 36
20	36 Tauri	6.0	14 12	97	15 11	245	0 59
23	47 Geminorum	6.0	5 43	102	6 31	254	0 48
24	λ Cancri	5.7	6 43	106	7 33	266	0 50
30	86 Virginis	5.9	16 57	89	17 59	351	1 02



PATH OF COMET *c* 1893 (BROOKS) THROUGH THE CONSTELLATIONS.

Comet *c* 1893 (Brooks).—The third comet of this year was discovered on the morning of Oct. 17 by Mr. W. R. Brooks of Smith Observatory, Geneva, N. Y. It was a telescopic comet, about as bright as a star of the seventh magnitude, with a distinct nucleus and a tail about 3° long. At Northfield, owing to bad weather and moonlight, we were unable to see the comet until the morning of Nov. 3 when its description was essentially the same as at the time of discovery. Professor Porter at the Cincinnati Observatory was able to get observations of its position

Oct. 18, 19, 21 and 23 and from these has computed the following elements and ephemeris, which have been printed in *Astronomical Journal* No. 306. These indicate that the comet passed perihelion Sept. 20 and is now receding from the Sun; but that it is approaching the Earth and will continue to approach us during November. Its theoretical brightness will slowly decrease during this time.

The course of the comet during November will be northeastward (celestial) through the constellations Coma Berenices, Canes Venatici and Boötes. This is shown in the accompanying diagram, in which the reader will be able to recognize the principal stars. During the latter part of the month the comet will be visible all night. On the 27th it will be quite near the last star (η) in the tail of the Great Bear.

Dr. B. A. Gould calls attention to the fact that the elements of this comet bear a striking resemblance to those of the first comet of 1864. It is too early yet to determine whether there is any possibility of their identity.

Prof. E. E. Barnard succeeded in photographing the comet on the morning of Oct. 19 with the 6-inch portrait lens of Lick Observatory. "The picture, although the exposure was short, and the comet very poorly placed, is a very successful one, and shows this object to possess characteristic features similar to those shown in the photographs of Swift's comet 1892 I.

The plate shows the tail to a distance of 3½°. This tail irregularly divides into two slightly divergent branches. There are two narrow straight rays springing out from the head on opposite sides and nearly symmetrical with the main tail. The north ray, which seems to leave the region of the nucleus, is inclined to the body of the comet by about 45°; the southern, which leaves the comet 10′ or 15′ minutes back of the head, is inclined about 30°. They are both about ½° long. There are faint evidences of several other rays from the southern side of the comet.

ELEMENTS OF COMET *c* 1893 (BROOKS) BY J. G. PORTER.

$$T = 1893 \text{ Sept. } 20.552 \text{ Berlin M. T.}$$
$$\left.\begin{aligned} \omega &= 350^\circ\ 40'.2 \\ \vee &= 175\ \ 19\ .3 \\ i &= 130\ \ 13\ .7 \end{aligned}\right\} 1893.0$$
$$\log q = 9.91968 \qquad q = 0.83115$$

EPHEMERIS FOR BERLIN MIDNIGHT.

	R. A.			Decl.			log Δ	log r.
	h	m	s	°	′			
Nov. 7	12	55	03	+28	48.9		0.1729	0.0806
11	13	03	19	32	24.0		.1597	.0982
15	13	12	35	36	14.3		.1470	.1155
19	13	23	08	40	19.9		.1353	.1324
23	13	35	20	44	39.9		.1250	.1468
27	13	49	42	+49	11.7		0.1169	0.1647

GENERAL NOTES.

Some of our enthusiastic readers say "Give us more illustration if you can." Haven't we done pretty well this time? Send us more subscribers and see what we will do.

The high commendation that we received from some very prominent astronomers in England in relation to the character of the first two numbers of this publication are gratifying indeed. Messrs. Wesley & Son of London recently ordered for seventeen annual subscribers.

Our space is much crowded this time and consequently our paragraph subjects are greatly limited in number. We have also been obliged to omit some useful comet notes and tables.

Naked-Eye Sun Spot.—Mr. O. R. Loomis of Bound Brook, N. J., writes that he saw a large sun spot with the naked eye October 25. He verified the observation with a 3-inch telescope. Examining our solar photographs of about the same date a large group of sun spots is noticed which were well defined and prominent between Oct. 21 and Oct. 27. The diameter of the group was more than 43,000 miles and covered the largest solar area about October 21.